Nativa, Sinop, v. 10, n. 3, p. 373-386, 2022.
Pesquisas Agrárias e Ambientais
DOI: https://doi.org/10.31413/nativa.v10i3.13913
ISSN: 2318-7670

Rainfall erosivity in municipalities of the Brazilian Cerrado Biome

Daniela CASTAGNA[1], Adilson Pacheco de SOUZA[1*], Laurimar Gonçalves VENDRUSCULO[2], Cornélio Alberto ZOLIN[2]

[1]Postgraduate Program in Environmental Sciences, Federal University of Mato Grosso, Sinop, MT, Brazil.
[2]Brazilian Agricultural Research Corporation (Embrapa Agrosilvopastoral), Sinop, MT, Brazil.
E-mail: pachecoufmt@gmail.com
ORCID: (0000-0002-6313-6437; 0000-0003-4076-1093; 0000-0002-3729-3455; 0000-0003-3028-8722)

Submitted on 05/31/2022; Accepted on 08/18/2021; Published on 08/19/2022.

ABSTRACT**:** The objective of this work was to estimate the rainfall erosivity in 101 municipalities in the Brazilian Cerrado biome. First, a filling of missing data was carried out for 81 rain gauge stations, with a 20-year historical series, in the states of Mato Grosso (MT), Mato Grosso do Sul (MS), Minas Gerais (MG), and Goiás (GO). The corrected data were subjected to 16 regionally calibrated equations, which enabled the determination of the rainfall erosivity. The results indicated that municipalities in northeastern MS present the highest monthly erosivity indexes (El_{30m}), reaching 2,796.5 MJ mm ha^{-1} h^{-1} year^{-1} in January, whereas the lowest index for this same month was 733.0 MJ mm ha^{-1} h^{-1} in the eastern MT. The rainfall annual erosivity, or R factor, varied between 3,713.1 and 12,345.6 MJ mm ha^{-1} h^{-1} year^{-1}, with the lowest values for municipalities in eastern MT and the highest values for those in northeastern MS. Although the municipalities studied are within the same biome, the spatial distribution makes them present regional effects due to different climatic factors, resulting in different rainfall volumes and intensities, which is reflected in the results of the monthly erosivity index and R factor.
Keywords: rainfall stations; R fator; fill missing data; precipitation.

Erosividade da chuva em municípios do Cerrado brasileiro

RESUMO: O objetivo deste trabalho é estimar a erosividade da chuva em 101 municípios localizados no bioma Cerrado. Para tanto, inicialmente foi realizado o preenchimento de falhas para 81 estações pluviométricas, com série histórica de 20 anos, localizadas nos estados de Mato Grosso, Mato Grosso do Sul, Minas Gerais e Goiás, posteriormente com os dados consistidos, foram aplicadas 16 equações calibradas regionalmente, permitindo determinada a erosividade da chuva. Os resultados apontaram que os municípios localizados na região Nordeste de MS, apresentam os maiores índices El30m, chegando a 2.796,5 MJ mm ha^{-1} h^{-1} ano^{-1} no mês de janeiro, enquanto para o mesmo mês, o menor índice foi de 733,0 MJ mm ha^{-1} h^{-1} no Leste de MT. A erosividade da chuva anual ou fator R variou entre 3.713,1 a 12.345,6 MJ mm ha^{-1} h^{-1} ano^{-1}, com os menores valores para os municípios da região Leste de MT e o maiores para a região Nordeste de MS. Apesar dos municípios estudados estarem localizados dentro do mesmo bioma, a distribuição espacial lhes confere influências regionais de fatores climáticos diferentes, ocasionando volumes e intensidades pluviométricas distintas, o que reflete no resultado no índice de erosividade mensal e no fator R.
Palavras-chave: estações pluviométricas; fator R; preenchimento de falhas; precipitação.

1. INTRODUCTION

Erosion is the process of soil disaggregation and transport and deposition of this material in a new place (BERTONI; LOMBARDI NETO, 2005). When it occurs naturally and slowly, shaping the landscape and assisting in soil formation, it is characterized as geological or natural erosion (POESEN, 2018).

Erosion can be divided into hydric and eolic erosions, which are caused by water and wind, respectively. Water erosion varies according to local edaphoclimatic characteristics and is dependent on factors connected to rainfall, soil, topography, soil cover, and management and conservationist practices, which have joint or isolated action and provide detachment, drag, and deposition of soil particles.

Losses from water erosion can be considered the main form of soil degradation (BERTOL et al., 2007) and a serious environmental and economic problem due to the impoverishment of soils, decreases in agricultural yields, aggradation of reservoirs and rivers, and pollution of water resources (CASSOL et al., 2008).

The determination or estimation of losses due to water erosion established in specific conditions of soil use, occupation, and management depends on the application of statistical and parametric models, such as the universal soil loss equation (USLE) (WISCHMEIER; SMITH, 1978). This is one of the most commonly used methods in the world for studies on soil loss, and it estimates soil erosion based on agents that cause or are determinants of erosion, such as soil erodibility, topographic factors, factors related to soil use and management, and rainfall erosivity.

Rainfall is the most important climatic factor among those that promote water erosion due to the impact of water drops and surface runoff, which are connected to interactions of the soil surface with the different types of rainfall in terms of rainfall volume and intensity (duration). Erosivity is the factor that presents the greatest temporal and spatial variations among those considered related to erosion by the USLE (SHIN et al., 2019). This index represents the capacity of rainfall to cause erosion in an area with no soil cover or protection due to the impact of raindrops on the bare soil (LOMBARDI NETO; MOLDENHAUER, 1992; NEARING et al., 2017).

Studies on erosivity have been carried out in different countries of the world (MEUSBURGER et al., 2012; PANAGOS et al., 2017; TALCHABHADEL et al., 2020; RIQUETTI et al., 2020). In Brazil, Oliveira et al. (2012) conducted a bibliographic survey and found that the spatial distribution of erosivity is lower in the Northeast region and higher in the extreme North. Almagro et al. (2017) estimated the erosivity for Brazil and developed predictions for climate change situations and their possible impacts on erosivity.

Studies were also conducted at lower scales for state and municipal levels (OLIVEIRA et al., 2012; AQUINO et al., 2014). Di Raimo et al. (2018) estimated the erosivity for the state of Mato Grosso and discussed the spatial distribution and the potential correlation of rainfall with latitude and phytophysiognomies of biomes in the state. Studies on erosivity are usually designed according to political borders, by countries, states, or municipalities, with no connection to natural limits, such as biomes to which the area belongs.

Erosivity analyses demand homogeneous and consistent rainfall data, which generate representative and reliable results. In Brazil, there is a national hydrometeorological network linked to official organs that make available rainfall data, among other information, through public portals, such as the Hidroweb, which shows information from 2,767 stations, and the Weather Databank for Teaching and Research (BDMEP), which shows information from more than 400 weather stations (HIDROWEB, 2021; BDMEP, 2021). However, the territorial distribution of these stations was dependent on the socioeconomic importance of the regions and access (logistics), resulting in a higher density of rain gauges and pluviographic stations in the South, Southeast, and Northeast regions of Brazil, whereas the North and Central-West regions present a smaller number of stations and shorter data period.

Moreover, the databases available on these portals may present consistency errors and missing data because of defects and calibration in the equipment and in the systems of collection, streaming, and storage of data or because of human errors, such as loss of records and errors of compilation or communication (BERTONI; TUCCI, 2007). These limitations can be solved through methodologies that allow the filling of missing data to improve the database consistency (OLIVEIRA et al., 2010).

In general, preliminary analyses of historical series of hydrometeorological data include the filling of missing data and verification of consistency, which denote the homogeneity of the available data. The filling of missing data in the temporal data series is based on correlations between the data of surrounding stations, which can be done by different methodologies, thus enabling the filling of gaps by using the model with better regional fit (OLIVEIRA et al., 2010; CARVALHO et al., 2017; IZZO et al., 2020).

The stations used for filling in missing data should be established in places with similar climate, relief, and vegetation characteristics, denoting hydrological similarity (LEIVAS et al., 2006). Methodologies for the use of simple or multiple linear regressions combined with regional weighting have been highlighted due to their easy application and satisfactory results for the filling of missing rainfall data (MELLO et al., 2017; NOR et al., 2020; CORDEIRO; BLANCO, 2021).

Brazil has a continental extension and, thus, has a high climate variety, which is strongly determinant for the diversity of soil, fauna, and flora, which determined the grouping of areas with homogeneous characteristics into six biogeographic zones or biomes: Amazon, Caatinga, Pampas, Pantanal, Atlantic Forest, and Cerrado (MMA, [s.d.]; ICMBIO, 2017).

The Cerrado is the second largest biome in Brazil; it is mainly in the Brazilian Central Highlands, encompassing 24% of the national territory, approximately 2,036,448 km² (IBGE, 2004). It has significant importance in terms of water contribution, encompassing river springs, such as those of the São Francisco, Paraíba, and Tocantins Rivers (OLIVEIRA et al., 2019), and contributes to eight of the twelve main hydrographic basins in Brazil, representing 71%, 94%, and 71% of the water source of the Araguaia-Tocantins, São Francisco, and Paraná-Paraguai basins, respectively (FELFILI et al., 2005; OVERBECK et al., 2015), and is an important recharge zone of the Guarani aquifer (OLIVEIRA et al., 2014).

The Cerrado is the savanna-like biome with the highest biodiversity in the world and high endemism; however, it is one of the world hotspots, mainly due to the loss of natural habitats because of changes in land cover and use connected to agriculture (MYERS et al., 2000; NEWBOLD et al., 2015). This biome encompasses most agricultural and livestock production in Brazil; despite presenting unfavorable natural soil characteristics (weathered and acidic soils with low nutrient contents), this production is promoted by the possibility of improving soil acidity and fertility and mechanization, which is favored by favorable relief and climate (KLINK; MACHADO, 2005).

The municipalities studied are in regions within the Cerrado biome with intense agriculture due to the favorable relief and climate conditions. In general, the climate in these regions is characterized by two well-defined seasons: dry (April to September) and rainy (October to March) (ALVAREZ et al., 2013; BECK et al., 2018). The rainy season peaks at the time that the soil is partially or completely uncovered due to the sowing seasons and phenology of agricultural crops and pastures, which, combined with the lack of adequate planning and soil management, can trigger erosive processes under intense rainfall and saturated soils. Understanding the erosivity intensity over the year in different places is important to avoid problems caused by erosion in the Cerrado biome in Brazil.

Therefore, the objective of this work was to estimate the rainfall erosivity for 101 municipalities in the states of Mato Grosso, Mato Grosso do Sul, Goiás, and Minas Gerais, according to data from rain gauge stations distributed spatially in the study area and to erosivity equations calibrated for each place.

2. MATERIALS AND METHODS

The study area encompasses 101 municipalities: 25 in the state of Mato Grosso (MT), 25 in Goiás (GO), 25 in Minas Gerais (MG), and 26 in Mato Grosso do Sul (MS) (Figure 1). They are mostly in the Cerrado biome, between the latitudes 11°43'S and 22°45'S and longitudes 44°00'W and 59°06'W.

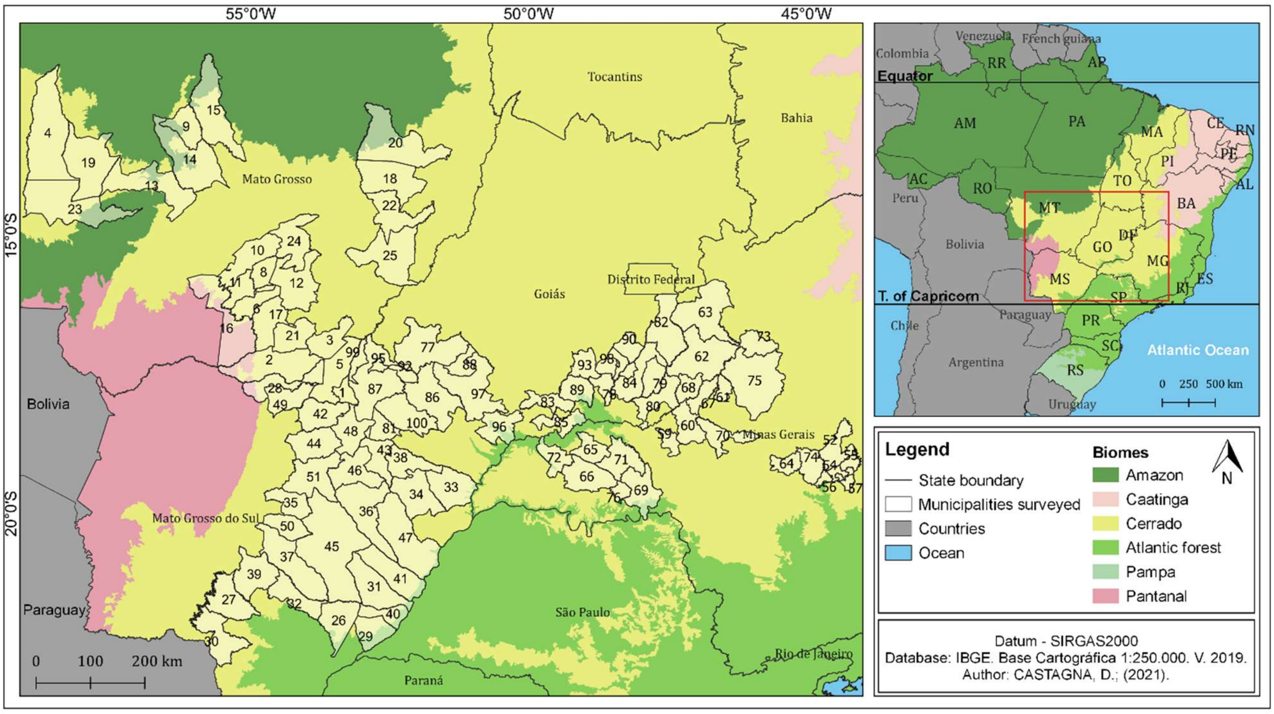

Figure 1. Location and spatial distribution of the studied municipalities in the Cerrado biome, Brazil.[1]
Figura 1. Localização e distribuição especial dos municípios estudados no bioma Cerrado, Brasil.

The municipalities were distributed in a region with climate variation, enabling the assessment of six different climates, according to the Köppen classification: tropical humid or subhumid (Am), tropical with dry winter (Aw), subtropical with hot summer (Cfa), temperate with mild summer (Cfb), subtropical with dry winter (Cwa), and subtropical highland (Cwb), with mean temperatures between 20 and 26 °C and rainfall depths between 1,000 and 2,500 mm (ALVARES et al., 2013).

The studied municipalities are part of the Sustainable Rural Project – Cerrado (SRP-Cerrado), whose objective is to decrease poverty, increase production, and mitigate the greenhouse gas effect through the adoption of low-carbon technologies and prevention of deforestation in the municipalities covered by the project (PRS, 2021). The SRP-Cerrado has financial support through a Technical Cooperation approved by the Inter-American Development Bank (IDB) with the International Climate Financing of the United Kingdom Government, whose institutional beneficiary is the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA), the Brazilian Institute for Development and Sustainability (IABS) is responsible for the administration, and the Rede ILPF Association is responsible for carrying out scientific coordination and technical support through the Brazilian Agricultural Research Corporation (EMBRAPA) (PRS, 2021).

2.1. Filling of missing data

Eighty-six rain gauge stations within the study area were used: 81 of them were considered for estimating erosivity, and five stations were used for support, i.e., the data were used for filling the missing data from other stations and not for erosivity estimation, as their location was in municipalities that had a second station with a lower quantity of missing data and that had a better data quality was chosen for estimating erosivity.

The temporal data series of all rain gauge stations evaluated covered a period of 20 years (1999 to 2019), except for the station in Sete Lagoas (MG), which covered 16 years (1999 to 2015). The rainfall data were acquired from the following platforms and selected according to the availability of data for each municipality (Figure 2 and Table 1): HIDROWEB, managed by the Brazilian National Water and Sanitation Agency (ANA); and BDMEP, databank of the Brazilian National Institute of Meteorology (INMET).

The spatial distribution analysis of rain gauge stations was carried out in the program QGIS v. 3.16.9, with the aid of the experimental plugin ANA Data Acquisition v. 0.2, to assess the proximity between stations.

According to the guide for instruments and weather observation methods of the WMO (2014), the spacing between stations should be 150 to 250 km to obtain good representativeness of the data. Thus, a buffer with a radius of 200 km surrounding the station to be corrected was used to assess the availability of support stations to obtain similar data for the filling of missing data. Three support stations were then selected to determine which data best represent the area of interest.

The data were obtained, and monthly missing data over the analyzed period were identified for each station; the month corresponding to the missing data to be corrected was also deleted in the support stations to obtain consistent, synchronized datasets. These datasets were divided into two groups: training/calibration of simple linear regression models (70%) and test/validation (30%).

Training, or calibration, is the procedure adopted to create the statistical model that will be applied. The test, or validation, refers to the remaining data subjected to application of the statistical model to assess its performance.

Linear regression is used to indicate the mathematical

[1]The municipality corresponding to the identification number present in Figure 1 can be found in Anexo A.

correlation between two variables to carry out predictions from this correlation (UYANIK; GÜLER, 2013; HOFFMANN, 2016). The linear regression method was used for filling the missing data due to the amount of data analyzed and its easy application; the methodology presented good results and was used with no need to test other methods.

Stations with missing data (response variable) were correlated to the respective support stations (predictor variable), focusing on the coefficients *a* and *b*, thus determining the equation (Equation 1):

$$y = a + b * x \qquad (01)$$

where: *y* is the dependent or response variable, *a* is the intercept, *b* is the angular coefficient, and *x* is the independent or predictor variable.

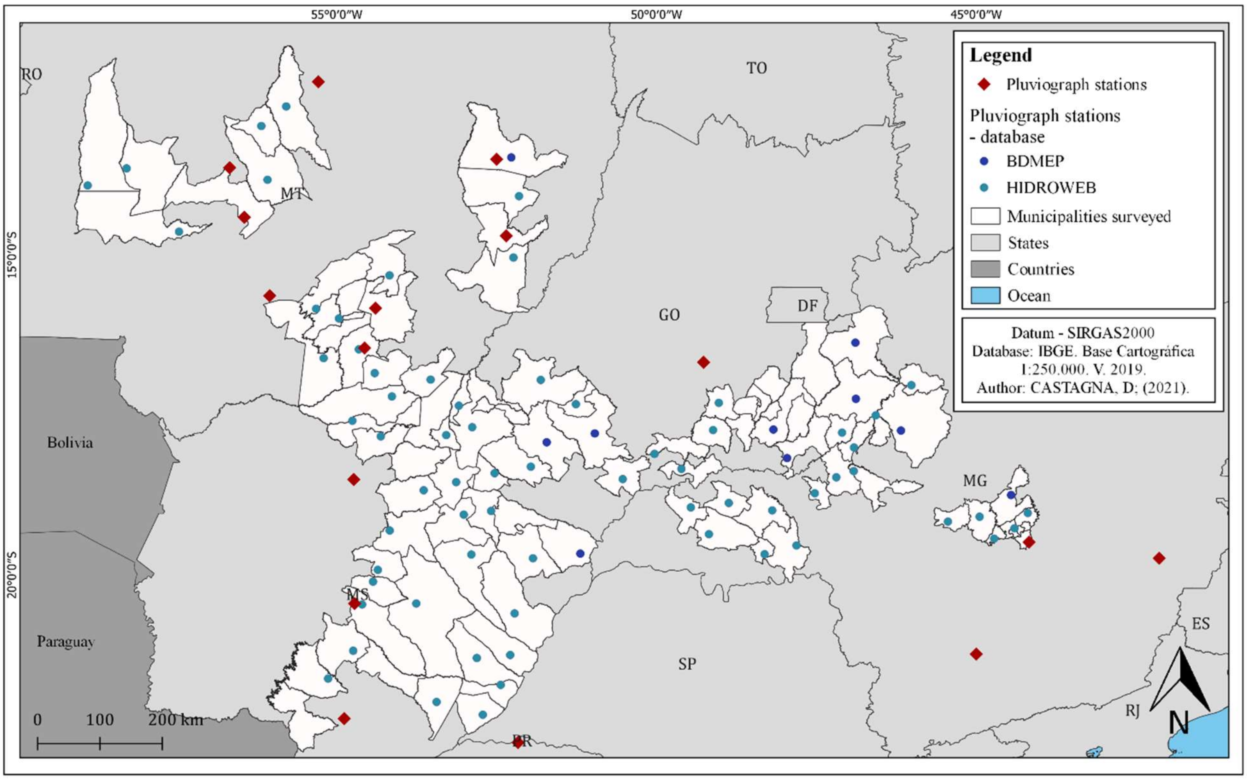

Figure 2. Location of the rain gauge stations used for analysis of rainfall distribution, classified according to the BDMEP databank (Brazilian National Institute of Meteorology - INMET) and HIDROWEB (managed by the Brazilian National Water and Sanitation Agency - ANA), and location of pluviographic stations that present a calibrated equation for calculating erosivity.

Figura 2. Localização das estações pluviométricas, utilizadas para análise da distribuição da precipitação, classificadas conforme o banco de dados BDMEP do INMET e HIDROWEB gerido pela ANA, e localização das estações pluviográficas que apresentam fórmula calibrada para o cálculo da erosividade.

The equation found for the training data for each support station was applied to the validation dataset, thus estimating the response values for the station with missing data. The statistical performance was evaluated following the methodology used in studies on weather data by applying statistical indicators: MBE (*Mean Bias Error*), RMSE (*Root Mean Square Error*) and Willmott agreement index (d) (WILLMOTT, 1981), to define statistical errors (over- or underestimates) and apply them for the filling of missing data (BADESCU, 2013; SOUZA et al., 2017).

MBE (Equation 2) shows the deviation of the mean of the estimated data from the data found, presenting a negative value when the estimated data are underestimated, a positive value when the estimated data are overestimated, and zero denotes a perfect simulation.

$$MBE = \frac{\sum_{i=1}^{N}(Pi - Oi)}{N} \qquad (02)$$

where: *N* is the number of observations, *Pi* is the estimated value and Oi is the measured value.

RMSE (Equation 3) indicates the actual spreads of errors of estimated values in relation to the values found and, different from MBE, does not indicate the underestimation or overestimation; however, the lower the value, or closer to zero, the better the performance.

$$RMSE = \left[\frac{\sum_{i=1}^{N}(Pi - Oi)^2}{N}\right]^{\frac{1}{2}} \qquad (03)$$

where: *N* is the number of observations, *Pi* are the estimated values, and *Oi* are the measured values.

The Willmott agreement index (Equation 4) indicates the fit of estimated values to the measured ones, varying from 0 to 1, corresponding to the worst and best fit, respectively.

$$d = 1 - \frac{\sum_{i=1}^{N}(Pi - Oi)^2}{\sum_{i=1}^{N}(|P\prime i| + |O\prime i|)^2} \qquad (04)$$

where: *N* is the number of observations, *Pi* are the estimated values, *Oi* is the measured values, $|P'i|$ is the absolute value of the difference, $Pi - \overline{Oi}$, and $|O'i|$ is the absolute value of the difference $Oi - \overline{Oi}$.

A ranking of statistical indicators was carried out to define which station presented the best filling of missing data (MBE, RMSE, and Willmott agreement index); weights of 1 to 3 were attributed for each indicator: 3 for the best and 1 for the worst result; the weights were added (considering the 3 indicators), and the station that presented the highest sum was defined as the best filling of missing data. In the case of a tie in the performance, the criterion used was the lowest distance between the station to be corrected and the support stations.

The procedures adopted allowed for the filling of missing data according to rain gauge stations with higher similarity, based on the statistical indicators used. A synthesis of the methodology used is shown in the flowchart in Figure .

Table 1. Location and identification of rain gauge stations evaluated and percentage of missing data in the databases.
Tabela 1. Localização e identificação das estações pluviométricas avaliadas e percentual de falhas nas bases de dados.

Identification [2]	Municipalities	States	Filling (%)	Latitude	Longitude
1853000(A1)	Alto Taquari	MT	12.7	-17.811388	-53.288888
1754000(A1)	Itiquira	MT	23.4	-17.207222	-54.138888
1653004(A1)	Alto Garças	MT	5.6	-16.943888	-53.533055
1358005(A1)	Sapezal	MT	16.3	-13.909722	-58.897222
1256002(A1)	Lucas do Rio Verde	MT	20.6	-12.979722	-56.180555
1555005(A1)	Campo Verde	MT	19.8	-15.836944	-55.323055
1554006(A1)	Jaciara	MT	13.1	-15.988333	-54.967222
83358(B2)	Poxoréu	MT	8.7	-15.827499	-54.395555
83309(B2)	Diamantino	MT	13.5	-14.406111	-56.446944
1356002(A1)	Nova Mutum	MT	14.7	-13.820555	-56.084166
1255001(A1)	Sorriso	MT	10.3	-12.674166	-55.791666
1655001(A1)	Santo Antônio do Leverger	MT	19.1	-16.608055	-55.206388
1654000(A1)	Rondonópolis	MT	11.5	-16.470555	-54.656388
1452004(A3)	Água Boa	MT	7.5	-14.076388	-52.150277
1358001(A1)	Campo Novo do Parecis	MT	5.2	-13.641666	-58.287500
83270(B2)	Canarana	MT	9.9	-13.470833	-52.271111
1654004(A1)	Pedra Preta	MT	13.1	-16.842222	-54.407222
83319(B2)	Nova Xavantina	MT	7.5	-14.697917	-52.350226
1457000(A1)	Tangara	MT	25.4	-14.631944	-57.468055
1554005(A1)	Primavera do Leste	MT	19.4	-15.314722	-54.175833
1552006(A1)	Barra do Garças	MT	13.9	-15.035555	-52.237499
2153003(A1)	Nova Andradina	MS	17.9	-21.981944	-53.439722
2155000(A1)	Maracaju	MS	13.5	-21.617222	-55.136388
1754002(A1)	Sonora	MS	17.5	-17.586944	-54.756666
2252000(A1)	Anaurilândia	MS	13.1	-22.181666	-52.716944
2152005(A1)	Santa Rita do Pardo	MS	6.8	-21.295000	-52.810277
83565(B2)	Paranaíba	MS	12.3	-19.663611	-51.191388
1951005(A1)	Inocência	MS	16.3	-19.736388	-51.932499
1954005(A1)	Bandeirantes	MS	8.7	-19.917777	-54.358611
1952001(A1)	Água Clara	MS	13.1	-19.678055	-52.896388
2054014(A1)	Campo Grande	MS	9.5	-20.458333	-54.604722
2154007(A1)	Sidrolândia	MS	14.3	-21.181388	-54.743888
2152001(A1)	Bataguassu	MS	9.1	-21.715833	-52.437222
2152014(A1)	Brasilândia	MS	20.6	-21.248333	-52.288055
1852002(A1)	Chapadão do Sul	MS	14.7	-18.996666	-52.587222
1853005(A1)	Figueirão	MS	12.7	-18.673611	-53.641388
2053000(A1)	Ribas do Rio Pardo	MS	11.5	-20.443333	-53.757500
1953004(A1)	Paraíso das Águas	MS	13.9	-19.054444	-53.014166
2052004(A1)	Três Lagoas	MS	15.1	-20.598333	-52.219444
1853004(A1)	Costa Rica	MS	10.3	-18.546666	-53.133888
1754004(A1)	Pedro Gomes	MS	15.9	-17.830833	-54.313055
2054019(A1)	Jaraguari	MS	13.1	-20.101666	-54.433611
1954006(A1)	Camapuã	MS	15.9	-19.302499	-54.172777
83536(B2)	Curvelo	MG	6	-18.747435	-44.454654
1944010(A1)	Paraopeba	MG	4.8	-19.268055	-44.401666
1944068(A1)	Cordisburgo	MG	12.7	-19.028888	-44.193888
1944049(A1)	Papagaios	MG	11.1	-19.428333	-44.719722
83586(B2)	Sete Lagoas	MG	6.4	-19.48454	-44.173798
1847000(A1)	Monte Carmelo	MG	17.9	-18.720555	-47.524444
1847008(A1)	Coromandel	MG	10.3	-18.471111	-47.188333
1746007(A1)	Lagoa Grande	MG	6	-17.502777	-46.571666
83479(B2)	Paracatu	MG	5.2	-17.244166	-46.881666
83428(B2)	Unaí	MG	10.7	-16.366286	-46.889321
1945035(A1)	Abaeté	MG	12.7	-19.163055	-45.442500
1848000(A1)	Monte Alegre de Minas	MG	11.1	-18.872222	-48.869444
1949002(A1)	Prata	MG	9.5	-19.359722	-49.180277
1846015(A1)	Vazante	MG	9.9	-18.004999	-46.911111
1747005(A1)	Guarda-Mor	MG	6	-17.772500	-47.098611

Table 1. Location and identification of rain gauge stations evaluated and percentage of missing data in the databases. **(CONTINUATION)**
Tabela 1. Localização e identificação das estações pluviométricas avaliadas e percentual de falhas nas bases de dados. **(CONTINUAÇÃO)**

Identification [2]	Municipalities	States	Filling (%)	Latitude	Longitude
1947026(A1)	Uberaba	MG	7.9	-19.535833	-47.811111
1846019(A1)	Patos de Minas	MG	5.6	-18.373611	-46.914999
1948006(A1)	Uberlândia	MG	15.9	-18.988333	-48.190277
1849000(A1)	Ituiutaba	MG	15.5	-18.941111	-49.463055
1746001(A1)	Brasilândia de Minas	MG	9.9	-17.030833	-46.013611
1944063(A1)	Pompeu	MG	9.1	-19.087222	-44.947222
83481(B2)	João Pinheiro	MG	15.5	-17.740277	-46.176944
1948003(A1)	Veríssimo	MG	16.3	-19.673055	-48.309722
1651000(A1)	Caiapônia	GO	25.4	-16.948888	-51.810277
83526(B2)	Catalão	GO	7.9	-18.170277	-47.958055
1852001(A1)	Chapadão do Céu	GO	22.6	-18.406666	-52.532499
1850001(A1)	Goiatuba	GO	15.9	-18.104722	-50.031388
83522(B2)	Ipameri	GO	5.6	-17.724527	-48.171916
1849016(A1)	Itumbiara	GO	10.7	-18.338888	-49.610833
83464(B2)	Jataí	GO	9.1	-17.923611	-51.717499
1752002(A1)	Mineiros	GO	14.7	-17.688055	-52.882777
1751004(A1)	Montividiu	GO	11.9	-17.328333	-51.260833
1749003(A1)	Morrinhos	GO	13.5	-17.732500	-49.115277
1749005(A1)	Piracanjuba	GO	17.1	-17.307222	-49.025555
1850002(A1)	Quirinópolis	GO	13.9	-18.498333	-50.528611
83470(B2)	Rio Verde	GO	9.1	-17.785277	-50.964722
1753002(A1)	Santa Rita do Araguaia	GO	11.1	-17.351944	-53.091388
1851005(A1)	Serranópolis	GO	14.3	-18.305000	-51.965833
1358002(A1)[3]	Sapezal	MT		-13.466666	-58.975000
1357001(A1)[3]	Campo Novo do Parecis	MT		-13.697777	-57.885277
1257000(A1)[3]	Brasnorte	MT		-12.116944	-57.999166
1846007(A1)[3]	Patos de Minas	MG		-18.841111	-46.550833
83423(B2)[3]	Goiânia	GO		-16.673055	-49.263888

Platform A for HIDROWEB and B for BDMEP, operator 1 CPRM, 2 INMET, and 3 UFC.[1] The identification of the municipalities studied is presented in Figure 1. [2] Identification number of rain gauge stations in the databanks to which they belong. [3] Rain gauge stations used only as support.
Plataforma "A" para HIDROWEB e "B" para BDMEP, operador "1" CPRM, "2" INMET e "3" UFC. [1] Identificador dos municípios estudados apresentados na Figure 1. [2] Número de identificação das estações pluviométricas nos bancos de dados as quais pertencem. [3] Estações utilizadas apenas como apoio.

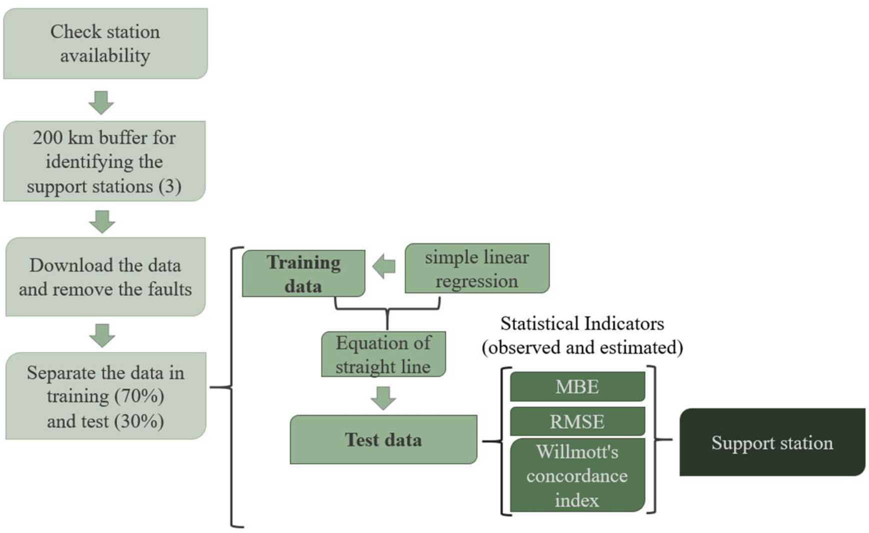

Figure 3. Flowchart of the methodological procedures adopted for the filling of missing data.
Figura 3. Fluxograma que ilustra os procedimentos metodológicos adotados para o preenchimento de falhas.

2.2. Erosivity

Wischmeier (1959) proposed estimating rainfall erosivity using the rainfall characteristics total kinetic energy (E) and maximum intensity in a 30-minute period (I_{30}) and their correlations with soil loss. The result of this interaction was termed the erosivity index (EI_{30}) since the monthly sum of the index for each rainfall event generates the monthly EI_{30}, and the sum of monthly values results in the annual EI_{30}. The mean of the annual erosivity indexes results in rainfall erosivity, i.e., the R factor of the universal soil loss equation (USLE) (WISCHMEIER; SMITH, 1978).

Data on rainfall intensity collected through pluviographic stations are needed to calculate rainfall erosivity. However, due to limitations of this type of data and the slowness of the process, some researchers calibrate the equations to use data from rain gauge stations, resulting in rainfall data with a longer interval (days, months, and years) and in a higher spatial availability of monitoring stations. Such equations were developed from the correlation between pluviographic and rainfall data, according to Lombardi-Neto (1977).

Bibliographical research was carried out to obtain equations already published and calibrated that can be applied to the areas covered by the present study (Table 3). Figure presents the spatial distribution of the rain gauge stations (represented by lozenges) that enabled the definition of the equations shown in Table 3.

Table 3. Erosivity equations available for applications in different municipalities of the Cerrado biome in Brazil.
Tabela 3. Equações de Erosividade disponíveis para aplicações em diferentes municípios do Cerrado brasileiro.

Municipalities	States	Equations	References
Canarana	MT	$EI30 = 12.18 (Rc^{0.622})$	Di Raimo et al (2018)
Cuiabá	MT	$EI30 = 244.47 (Rc^{0.508})$	
Diamantino	MT	$EI30 = 51.46 (Rc^{0.883})$	
Vera (Gleba Celeste)	MT	$EI30 = 171.29 (Rc^{0.605})$	
Nova Xavantina	MT	$EI30 = 96.36 (Rc^{0.517})$	
Poxoréu	MT	$EI30 = 156.38 (Rc^{0.552})$	
Rondonópolis	MT	$EI30 = 167.16 (Rc^{0.567})$	
São José do Rio Claro	MT	$EI30 = 126.76 (Rc^{0.464})$	
Dourados	MS	$EI30 = 80.305 (Rc^{0.8966})$	Oliveira et al. (2012)
Coxim	MS	$EI30 = 138.33 (Rc^{0.7431})$	
Campo Grande	MS	$EI30 = 139.44 (Rc^{0.6784})$	
Goiânia	GO	$EI30 = 215.33 + 30.23 (Rc)$	Silva et al. (1997)
Lavras	MG	$EI30 = 85.672 (Rc^{0.6557})$	Aquino et al. (2014)
Sete Lagoas	MG	$EI30 = 25.3 + 43.35 (Rc) – 0.232 (Rc^2)$	De Sá et al. (1998)
Caratinga	MG	$EI30 = 321.63 (Rc^{0.48})$	Silva et al. (2010)
Teodoro e Sampaio	SP	$EI30 = 106.8183 + 46.9562 (Rc)$	Colodro et al. (2002)

All the equations found require the rainfall coefficient (Rc), which was determined according to the equation proposed by Lombardi-Neto (1977):

$$Rc = \frac{p^2}{P} \quad (05)$$

where: p is the mean monthly rainfall (mm month^{-1}) and P is the mean annual rainfall (mm year^{-1}).

The definition of the erosivity equation to be used for each rain gauge station was based on the methodology used by Di Raimo et al. (2018). The correlation (R) was carried out for the following data: (i) monthly rainfall, (ii) mean monthly rainfall, and (iii) rainfall coefficient (RC), comparing data from the rain gauge station with those from the three closest pluviographic stations using the calibrated equation.

The correlations between the mean monthly rainfall and rainfall coefficient (RC) were classified by attributing weights of 1, 2, and 3: 3 representing the best and 1 the worst result. Monthly rainfall had a higher quantity of factors for correlation because it corresponds to all months over the studied period; thus, it was attributed higher weights (2, 4, and 6): 6 representing the best, and 2 the worst result.

The weights attributed to the correlations were added, resulting in a performance factor that determined which equation to use. In the case of a tie in the performance, the criterion used was the shortest distance between the rain gauge and the pluviographic station.

The distribution of erosivity over the entire study area was determined by interpolating the values found for the stations using the inverse distance weighted (IDW) method, which consists of attributing weighted values according to the distance from the sampled points, as an area closer to the sample has higher weight than more distant areas (ANGULO-MARTÍNEZ et al., 2009; ZHU et al., 2019).

3. RESULTS

The filling of missing data, determined by calculating the coefficients of determination (R^2) and coefficients a and b and using the statistical indicators between the correlations generated among the support stations, is shown in Annex B.

The coefficients of determination of 81 rain gauge stations varied, in general, from 0.7 to 0.9, except for the station in Anaurilândia, which presented a coefficient of correlation higher than 81%. Regarding the MBE indicator, 45% of the models underestimated the total monthly rainfall, with variations between -0.001 and -19.3 mm; overestimates were generated by 55% of the simple linear regressions, with variations between 0.04 and 11.1 mm. The RMSE indicator showed variations from 20.8 to 56.4 mm, whereas the Willmott agreement index showed variations from 0.90 to 0.98.

The mean annual rainfall, according to the 81 rain gauge stations, was 1,445.0±173.0 mm. The mean for the rainy period (October to March) was 1,219.1±159.5 mm, and the mean for the dry period (April to September) was 225.9±82.3 mm.

When the stations were segmented according to the states in which they were installed, the data showed similarity in rainfall distribution over the year, with a period of greater rainfall volume between October and March and a period of lower rainfall volume between April and September, presenting higher dispersion of data in the rainy period than in the dry period. However, they presented differences in rainfall distribution and volume over the months (Figure 4).

According to the rainfall data by state, Minas Gerais had the lowest mean annual rainfall, 1,300.3 mm, followed by Mato Grosso do Sul, Goiás, and Mato Grosso, which presented 1,429.6, 1,454.5, and 1,612.9 mm, respectively (Figure 4).

Despite having the second lowest mean annual rainfall, Mato Grosso do Sul was the state with the highest rainfall volume (329.0 mm) in the dry season (April to September), when approximately 23% of the total annual rainfall occurs, while this percentage is between 11% and 13% of the total annual rainfall in the other states studied (Figure 4).

Variations in monthly rainfall reflect erosivity, indicating a higher data dispersion in the rainy period and a lower dispersion in the dry period. In addition, the erosivity in February and March presented a difference of only 14.9 MJ mm ha^{-1} h^{-1} year^{-1} in the means, and the outliers in these months reached similar values; it resulted in greater rainfall volume for the states of Goiás and Minas Gerais in March than in February, and the opposite occurred for the states of Mato Grosso and Mato Grosso do Sul, which presented the greatest rainfall volume in February (Figure 4 and Figure 5).

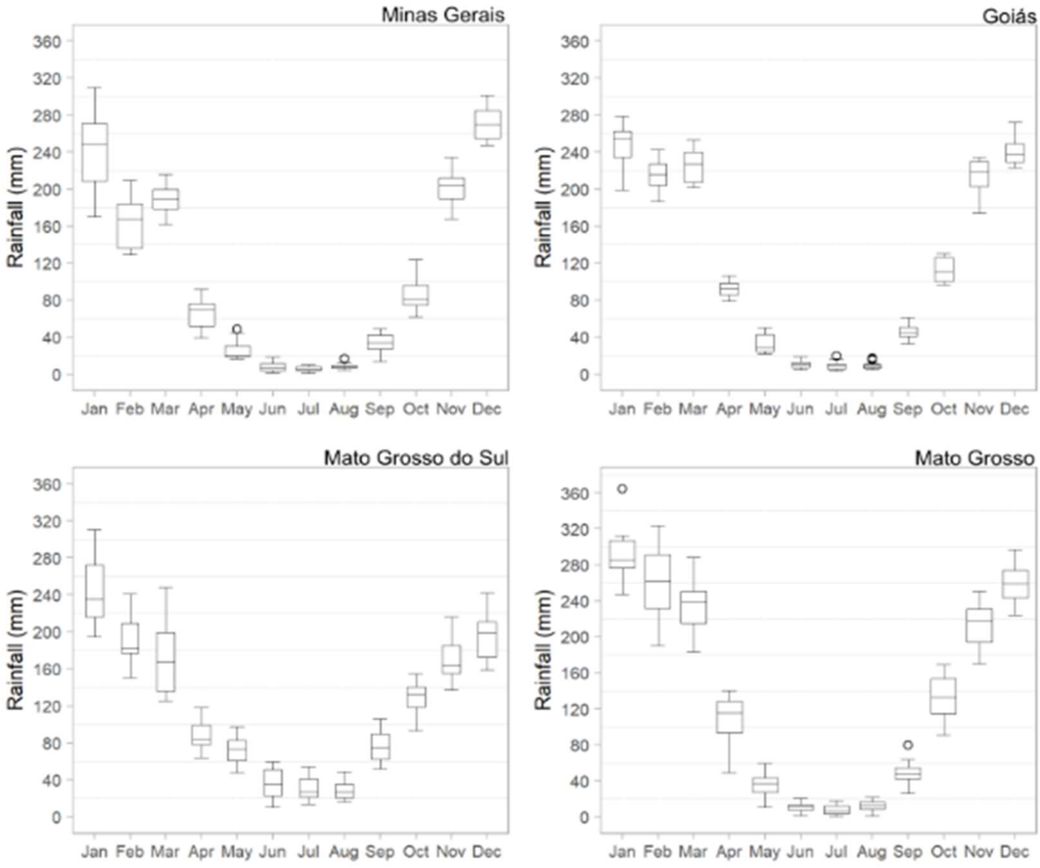

Figure 4. Boxplot for monthly rainfall considering 81 rain gauge stations in areas in the Cerrado biome, grouped according to the state in which they were installed. The box represents the interquartile interval, the line inside is the median, the bars are the lower and upper limits, and the dots outside the box are the outliers.
Figura 4. Boxplot referente a precipitação pluvial mensal considerando 81 estações pluviométricas localizadas em área de Cerrado, agrupados de acordo com o estado em que está instalada. A caixa representa o intervalo interquartil, a linha no interior é a mediana, as hastes são os limites inferiores e superiores e os pontos externos à caixa são os outliers.

According to the erosivity data (Figure 5), 87.2% of all erosivity occurs in the rainy season, mainly in January and December, when 38.1% of the annual erosivity occurs with means of 1,533 and 1,389.6 MJ mm ha^{-1} h^{-1} year^{-1}, respectively. July and August were the months with the lowest erosivity means, presenting the same value: 76.2 MJ mm ha^{-1} h^{-1} year^{-1} (Figure 5).

The outliers found in 5, referring to January, February, March, and November, are also shown in the spatial distribution of erosivity data in Figure 6 e Figure 7.

Figure 6 e Figure 7 show the distribution of monthly erosivity indexes (EI_{30m}) for the municipalities studied. January (Figure 66) showed higher erosivity in the municipalities in northeastern Mato Grosso do Sul and southwestern Goiás and lower erosivity in those in eastern Mato Grosso. February (Figure 66) showed a decrease in these indexes and lightening of higher erosivity points, and the municipalities of the central-north region of Mato Grosso presented the highest values.

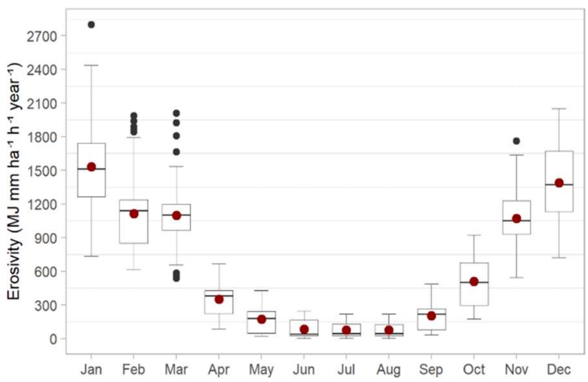

Figure 5. Boxplot for the monthly erosivity index (EI_{30m}) in 101 Brazilian municipalities in the states of MS, MT, MG, and GO within the Cerrado biome. The box represents the interquartile interval, the line inside is the median, the bars are the lower and upper limits, dots outside the box are the outliers, and the dot inside the box is the mean.
Figura 52. Boxplot referente ao Índice de erosividade mensal (EI_{30m}) em 101 municípios do Cerrado brasileiro nos estados de MS, MT, MG e GO. A caixa representa o intervalo interquartil, a linha no interior da caixa é a mediana, as hastes são os limites inferiores e superiores, os pontos externos à caixa são os outliers e o ponto interno é a média.

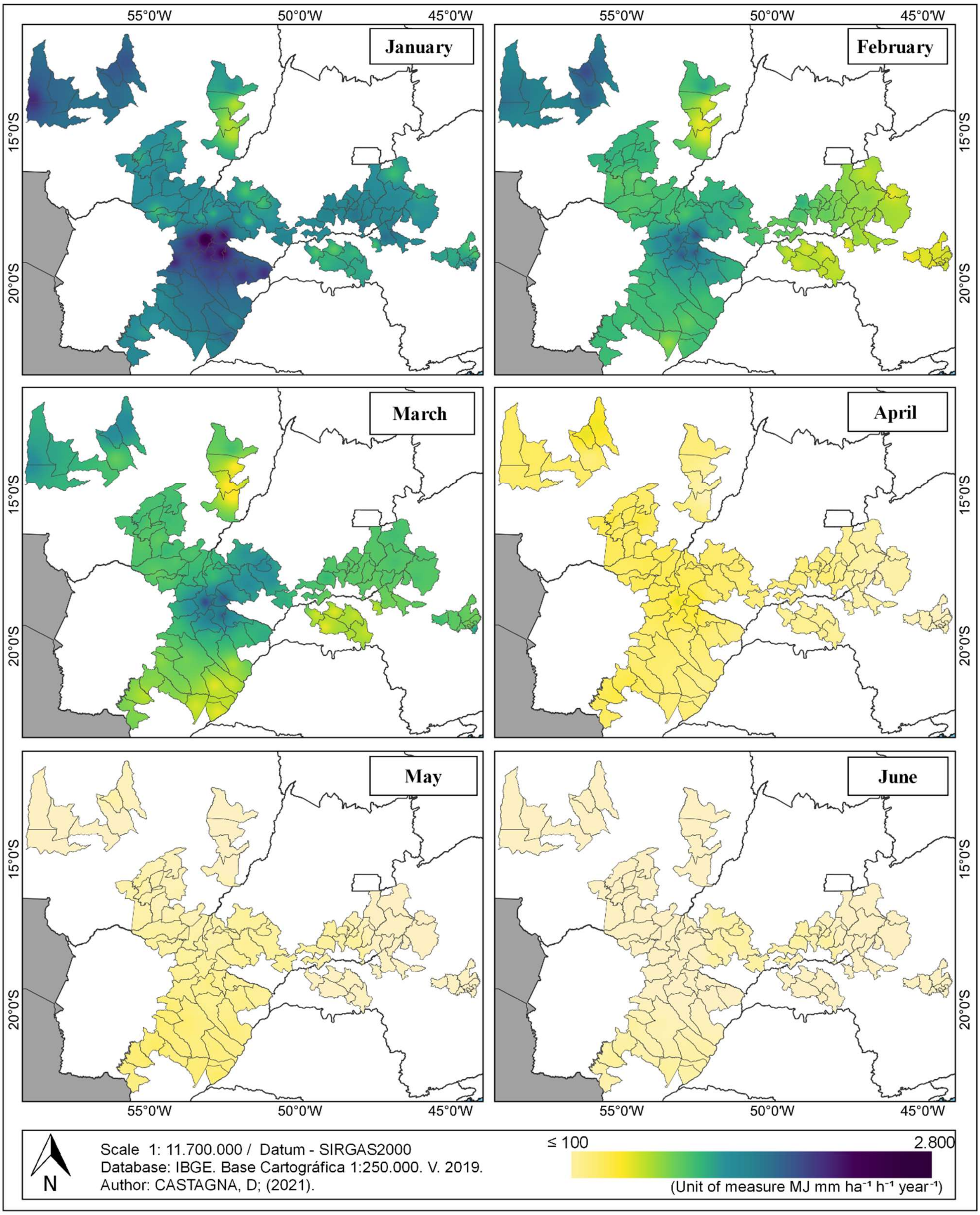

Figure 6. Spatialization of the monthly erosivity index (EI_{30m}) for 101 Brazilian municipalities in the Cerrado biome from January to July.
Figura 6. Espacialização do índice de erosividade mensal (EI_{30m}) em 101 municípios do Cerrado brasileiro, de janeiro à julho.

April to September showed a homogenization of $EI_{30\ m}$ for all regions studied (Figure 66 and Figure7), with decreases over the dry period. September showed increases in erosivity in municipalities in the central-north region of Mato Grosso and the central region of Mato Grosso do Sul when compared to the other municipalities. The erosivity increased from November onward, with the highest values found for the central and western regions of Minas Gerais and eastern Goiás (Figure7).

4. DISCUSSION

The lowest annual erosivity in the region studied was found for eastern Mato Grosso, and the highest was found for northeastern Mato Grosso do Sul (Figure 8). The municipalities in Mato Grosso do Sul showed a variation of 6,725.09 to 12,323 MJ mm ha^{-1} h^{-1} $year^{-1}$, with the highest erosivity found for the northeastern region of the state (between 10,000 and 12,323 MJ mm ha^{-1} h^{-1} $year^{-1}$) and the lowest for the municipalities in the east; the other municipalities in the state present values between 9,000 and 8,000 MJ mm ha^{-1} h^{-1} $year^{-1}$. These results are consistent with those found by Oliveira et al. (2012).

The spatialization of the values found for the municipalities in Mato Grosso, with higher indexes for the central-north and lower indexes for the east region, is consistent with the results found by Di Raimo et al. (2018); however, there were differences in the actual values, as the lowest index found by them was 4,904 MJ mm ha^{-1} h^{-1} $year^{-1}$, whereas that found in the present work was 3,713.12 MJ mm ha^{-1} h^{-1} $year^{-1}$ (for Barra do Garças).

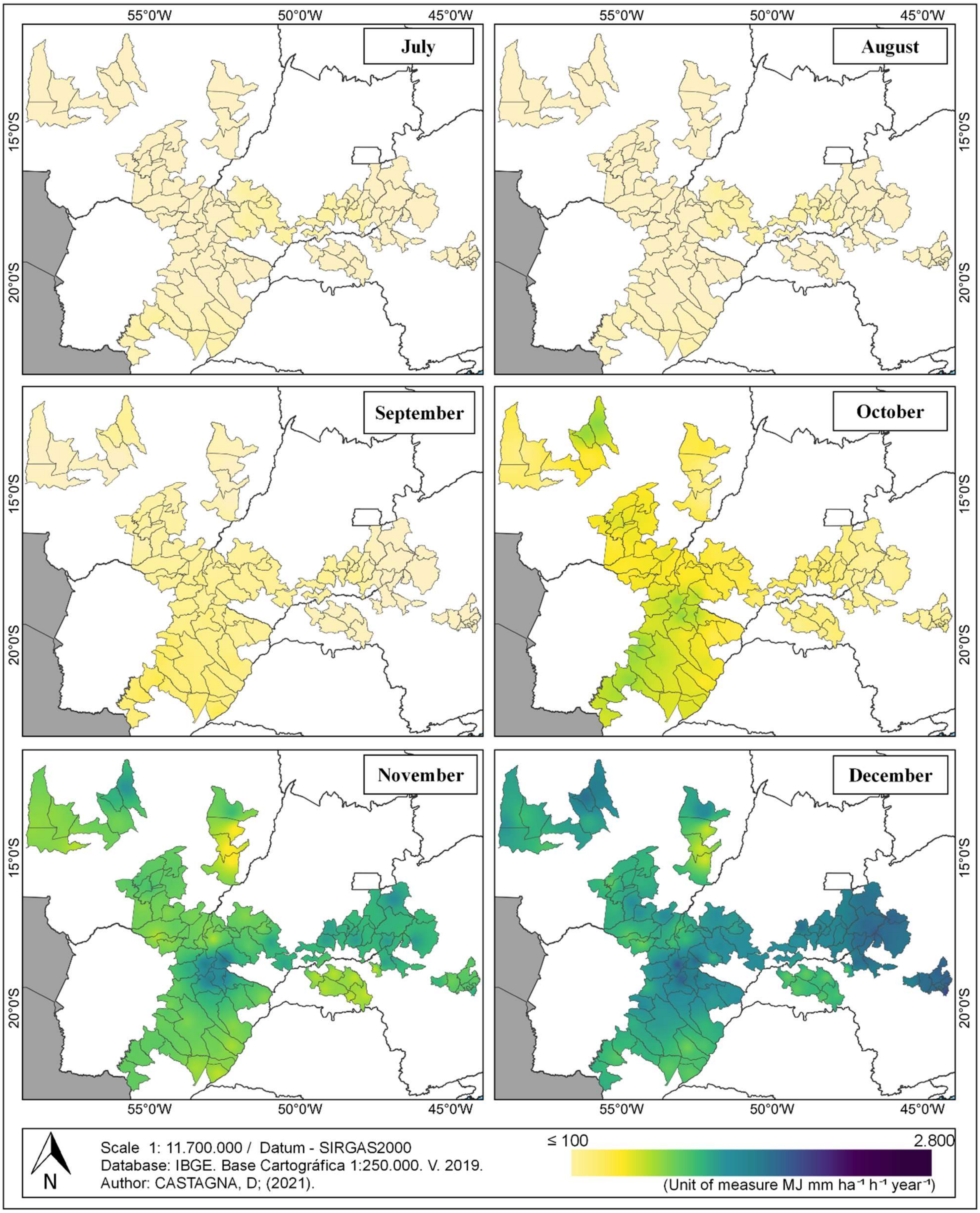

Figure 7. Spatialization of the monthly erosivity index (EI_{30m}) in 101 Brazilian municipalities of the Cerrado in Brazil from July to December.
Figura 7. Espacialização do índice de erosividade mensal (El30m) em 101 municípios do Cerrado brasileiro, de julho à dezembro.

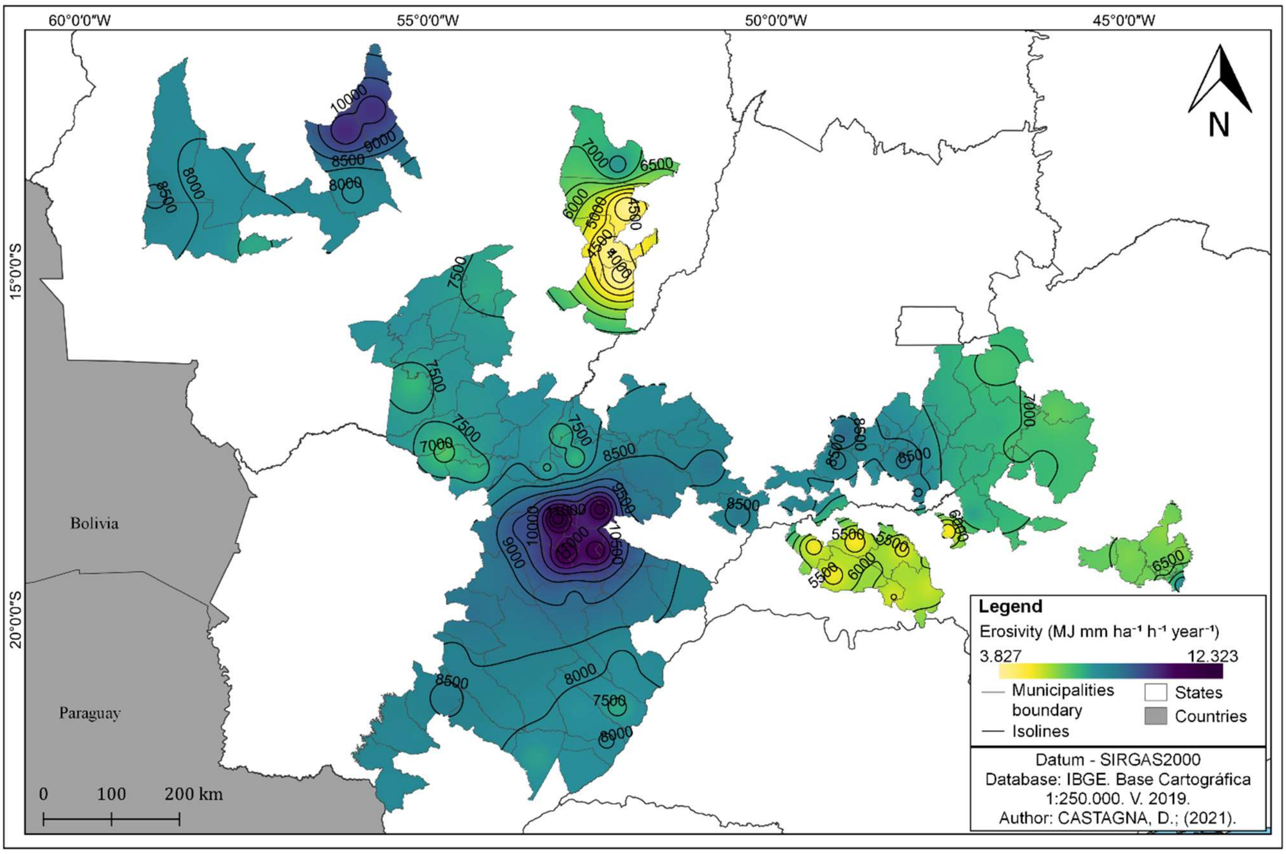

Figure 8. Spatialization of rainfall erosivity, or R factor, in 101 Brazilian municipalities in the Cerrado biome, based on 81 rain gauge stations and 16 regionally calibrated erosivity equations.

Figura 8. Espacialização da erosividade da chuva ou fator R em 101 municípios do Cerrado brasileiro, baseado 81 estações pluviométricas e 16 fórmulas de erosividade calibradas regionalmente.

The municipalities in Goiás generally had a variation between 7,136.66 and 11,755.65 MJ mm ha^{-1} h^{-1} $year^{-1}$, which is a similar result to that found by Oliveira et al. (2012) and Silva et al. (1997).

The municipalities in Minas Gerais showed variation between 5,068.55 and 7,802.80 MJ mm ha^{-1} h^{-1} $year^{-1}$, which is also a similar result to that estimated by De Sá et al. (1998) for Sete Lagoas (5,835 MJ mm ha^{-1} h^{-1} $year^{-1}$) and by Mello et al. (2007) for the whole state (5,000 to 12,000 MJ mm ha^{-1} h^{-1} $year^{-1}$).

The highest indexes were found for the municipalities of Chapadão do Sul (MS), Paraíso das Águas (MS), Costa Rica (MS), and Chapadão do Céu (GO); in these cases, the equation and EI_{30} applied were those calibrated for Coxim (MS), denoting a need for calibration of new regional coefficients, although they are consistent with the observations of Oliveira et al. (2012).

The studied region is under intensive agricultural exploitation with commodities such as maize and soybean, whose planting is carried out between September and December and the harvest between January and April (CONAB, 2019), which are precisely the periods with the highest monthly erosivity indexes. And, the municipalities of Chapadão do Sul (MS), Costa Rica (MS) and Chapadão do Céu (GO), Sorriso (MT) and Lucas do Rio Verde (MT) that have the highest R Factor, are among the 100 municipalities with the highest national agricultural production (MAPA, 2022).

In this case, the use of conservationist practices, such as vegetation cover between rows and between crop seasons, would avoid exposure of soil at times with no or lower soil cover by the implemented crops, minimizing the erosive effects of rainfall.

Rainfall erosivity, combined with fragile soils susceptible to erosion, uneven topography, and inadequate management, can cause erosive processes that affect agricultural production systems due to the loss of water, soil, nutrients, and carbon and environmental problems such as aggradation and contamination of water bodies.

Therefore, the use of conservationist practices is important, which includes the maintenance of plant covers that protect the soil through afforestation or reforesting in cases of soils with low agricultural suitability and highly susceptible to erosion, implementation of well-managed pastures, use of cover plants between rows and between crop seasons, planting of crops in contour banks, terracing, and use of no-tillage systems (BERTONI; LOMBARDI NETO, 2005; ZONTA et al., 2012).

5. CONCLUSIONS

The filling of missing data using linear regression was enough to present good results, allowing the obtaining of erosivity values consistent with the literature, denoting that, sometimes, the use of simpler methodologies is justified in situations with a large amount of data, such as those used in the present work.

Regarding erosivity, there is a variation in regional rainfall characteristics, generating an annual erosivity of 3,713.12 to 12,345.572 MJ mm ha^{-1} h^{-1} $year^{-1}$. Although the evaluated municipalities are in the same biome and within the same climatic domain, different factors, such as relief and air masses, affect their rainfall characteristics due to their spatial distribution.

Information on the EI_{30m} and erosivity values is important to design and plan strategies to mitigate or avoid the erosive effect of rainfall, including the maintenance of natural cover plants and implementation of production systems that prevent the direct impact of rainfall on the soil, mainly in periods with high erosivity intensities.

6. ACKNOWLEDGMENTS

The authors thank the Graduate Program in Environmental Sciences of the University of Mato Grosso for providing quality information for this study.

This research was developed within the scope of the Sustainable Rural Project – Cerrado (SRP-Cerrado), financed by the Technical Cooperation approved by the Inter-American Development Bank (IDB) with resources of the International Climate Financing of the United Kingdom Government, whose institutional beneficiary is the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA). The Brazilian Institute for Development and Sustainability (IABS) is responsible for the administration and achievement of the project, and the Rede ILPF Association is responsible for carrying out scientific coordination and technical support through the Brazilian Agricultural Research Corporation (EMBRAPA) (PRS, 2021).

7. REFERENCES

ALMAGRO, A.; OLIVEIRA, P.T.S.; NEARING, M.A.; HAGEMANN, S. Projected climate change impacts in rainfall erosivity over Brazil. **Scientific Reports**, v. 7, p. 1-12, 2017. DOI: 10.1038/s41598-017-08298-y

ALVAREZ, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. de M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013. DOI: 10.1127/0941-2948/2013/0507

ANGULO-MARTÍNEZ, M.; LÓPEZ-VICENTE, M.; VICENTE-SERRANO, S. M.; BEGUERÍA, S. Mapping rainfall erosivity at a regional scale: a comparison of interpolation methods in the Ebro Basin (NE Spain). **Hydrololgy and Earth System Sciences**, v. 13, p. 1907-1920, 2009. DOI: 10.5194/hess-13-1907-2009.

AQUINO, R. F.; SILVA, M. L. N.; FREITAS, D. A. F. D.; CURI, N.; MELLO, C. R. D.; AVANZI, J. C. Erosividade das chuvas e tempo de recorrência para Lavras, Minas Gerais. **Revista Ceres**, v. 61, p. 09-16, 2014.

BADESCU, V. Assessing the performance of solar radiation computing models and model selection procedures. **Journal of Atmospheric and Solar-Terrestrial Physics**, v. 105-106, p. 119-134, 2013. DOI: 10.1016/j.jastp.2013.09.004

BECK, H.; ZIMMERMANN, N.; MCVICAR, T.; VERGOPOLAN, N.; BERG, A.; WOOD, E. F. Present and future Köppen-Geiger climate classification maps at 1-km resolution. **Science Data**, n. 5, p. 1-12, 2018. DOI: doi.org/10.1038/sdata.2018.214

BERTOL, I.; COGO, N. P.; SCHICK, J.; GUDAGNIN, J. C.; AMARAL, A. J. Aspectos financeiros relacionados às perdas de nutrientes por erosão hídrica em diferentes sistemas de manejo do solo. **Revista Brasileira de Ciência do Solo**, v. 31, p. 133-142, 2007.

BERTONI, J.; LOMBARDI NETO, F. **Conservação do Solo**. 5 ed. São Paulo: Editora Ícone, 2005. 392p.

BERTONI, J.C.; TUCCI, C. E. M. Precipitação. In: TUCCI. C. E. M. **Hidrologia: Ciência e aplicação**. 4 ed. Porto Alegre: UFRGS. 2007. p. 177-241.

CARVALHO, J. R. P. de; MONTEIRO, J. E. B. A.; NAKAI, A. M.; ASSAD, E. D. Model for Multiple Imputation to Estimate Daily Rainfall Data and Filling of Faults. **Revista Brasileira de Meteorologia**, v. 32, n. 4, p. 575-583, 2017. DOI: 10.1590/0102-7786324006

CASSOL, E. A.; ELTZ, F. L. F.; MARTINS, D.; LEMOS, A. M.; LIMA, V. S.; BUENO, A. C. Erosividade, padrões hidrológicos, período de retorno e probabilidade de ocorrência das chuvas em São Borja, RS. **Revista Brasileira de Ciência do Solo**, v. 32, p. 1239-1251, 2008.

COLODRO, G.; CARVALHO, M. P.; ROQUE, C. G.; PRADO, R. M. Erosividade da chuva: distribuição e correlação com a precipitação pluviométrica de Teodoro Sampaio (SP). **Revista Brasileira de Ciência do Solo**, v. 26, p. 809-818, 2002.

CONAB_Companhia Nacional de Abastecimento. **Calendário de plantio e colheita de grãos no Brasil 2019**. Disponível em: < https://www.conab.gov.br/outras-publicacoes/item/download/28424_34d371f808b23d9bd37b9101c8ed5094>. Acesso em: 20 de julho de 2021.

CORDEIRO, A. L. de M.; BLANCO, C. J. C. Assessment of satellite products for filling rainfall data gaps in the Amazon region. **Natural Resource Modeling**, v. 34, n. 2, p. 1-21, 2021. DOI: 10.1111/nrm.12298

DE SÁ, J. J. G.; MARQUES, M.; ALVARENGA, R. C.; CURI, N. Erosividade das chuvas da região de Sete Lagoas, MG. **Pesquisa Agropecuária Brasileira**, v. 33, n. 5, p. 761-768, 1998.

DI RAIMO, L. A. DI L.; AMORIM, R. S. S.; COUTO, E. G.; NÓBREGA, R. L. B.; TORRES, G. N.; BOCUTI, E. D.; ALMEIDA, C. O. S.; RODRIGUES, R. V. Spatio-temporal variability of erosivity in Mato Grosso. Brazil. **Revista Ambiente e Água**, v. 13. n. 6. p. 1- 14. 2018. DOI: 10.4136/1980-993X

FELFILI, J. M.; SOUSA-SILVA, J. C.; SCARIOT, A. Biodiversidade, ecologia e conservação do Cerrado: avanços no conhecimento. In: FELFILI, J. M.; SOUSA-SILVA, J. C.; SCARIOT, A. (org.). **Cerrado: Ecologia, Biodiversidade e Conservação**. Brasília: Ministério do Meio Ambiente, 2005. cap. Síntese, p. 25- 44.

HIDROWEB. 2021. Disponível: https://www.snirh.gov.br/hidroweb/apresentacao.

HOFFMANN, R. **Análise de regressão: uma introdução à Econometria**. 5 ed. Piracicaba: ESALQ/USP. p. 393. 2016. DOI: 10.11606/9788592105709

IBGE_Instituto Brasileiro de Geografia e Estatística. **Biomas do Brasil** – 1:5.000.000, Síntese Descrição do Biomas, 2004. Disponível em: https://www.ibge.gov.br/geociencias/informacoes-ambientais/estudos-ambientais/15842-biomas.html?edicao=16060&t=downloads. Acesso em: 10 ago. 2021.

ICMBIO_Instituto Chico Mendes de Conservação da Biodiversidade. A pluralidade dos biomas preservados pelo ICMBio, 2017. Disponível em:

https://www.icmbio.gov.br/portal/ultimas-noticias/20-geral/8797-a-pluralidade-dos-biomas-preservados-pelo-icmbio. Acesso em: 10 ago. 2021.

INMET_Instituto Nacional de Meteorologia. 2021. Disponível: https://portal.inmet.gov.br/.

IZZO, M.; AUCELLI, P. PC.; MARATEA, A. Historical trends of rain and air temperature in the Dominican Republic. **International Journal of Climatology**, v. 41, n. 1, p. 563-581, 2020. DOI: 10.1002/joc.6710

KLINK, C. A.; MACHADO, R. B. A conservação do Cerrado brasileiro. **Megadiversidade**, Belo Horizonte: Conservação Internacional, v. 1, n. 1, p. 147-155, 2005.

LEIVAS, J. F.; BERLATO, M. A.; FONTANA, D. C. Risco de deficiência hídrica decendial na metade sul do Estado do Rio Grande do Sul. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 10, n. 2, p. 397-407, 2006. DOI: 10.1590/S1415-43662006000200022

LOMBARDI NETO, F. **Rainfall erosivity** - its distribution and relationship with soil loss at Campinas, Brasil. West Lafayette, Purdue University, 1977. 53p. (Tese de Mestrado).

LOMBARDI NETO, F.; MOLDENHAUER, W. C. Erosividade da chuva: sua distribuição e relação com as perdas de solo em Campinas (SP). **Bragantia**, v. 51, p.189-196, 1992.

MAPA_Ministério da Agricultura Pecuária e Abastecimento. Nota nº 01-2022/CGPLAC/DAEP/SPA/MAPA. Brasília, jan. 2022. Disponível em: http://astecna.com.br/wp-content/uploads/2022/01/doc-ministeriodaagricultura-municipiosmaisricosdoagro.pdf.

MELLO, Y. R. de.; KOHLS, W.; OLIVEIRA, T. M. N. de. Uso de diferentes métodos para o preenchimento de falhas em estações pluviométricas. **Boletim Geográfico**, v. 35. n. 1. p. 112-121. 2017. DOI: 10.4025/bolgeogr.v35i1.30893

MELLO, C. R. de; SÁ, M. A. C. de; CURI, N.; MELLO, J. M. de; VIOLA, M. R.; SILVA, A. M. da. Erosividade mensal e anual da chuva no Estado de Minas Gerais. **Pesquisa Agropecuária Brasileira**, Brasília, v. 42, p. 537-545, 2007. DOI: 10.1590/S0100-204X2007000400012

MEUSBURGER, K.; STEEL, A.; PANAGOS, P.; MONTANARELLA, L.; ALEWELL, C. Spatial and temporal variability of rainfall erosivity factor for Switzerland. **Hydrololgy and Earth System Sciences**, v. 16, p. 167-177, 2012. DOI: 10.5194/hess-16-167-2012

MMA_Ministério do Meio Ambiente, [s.d]. Disponível em: https://antigo.mma.gov.br/biodiversidade/biodiversidade-brasileira.html. Acesso em: 05 de set. de 2021.

MYERS, N.; MITTERMEYER, R. A.; MITTERMEYER, C. G.; FONSECA, G. A.; KENT, J. Biodiversity hotspots for conservantion priorites. **Nature**, v. 403, p. 853-858, 2000. DOI: 10.1038/35002501

NEARING, M. A.; YIN, S.; BORRELLI, P.; POLYAKOV, V. O. Rainfall erosivity: Na historical review. **Catena**, v. 157, p. 357-362, 2017. DOI: 10.1016/j.catena.2017.06.004

NEWBOLD, T. et al. Global effects of land use on local terrestrial biodiversity. **Nature**, v. 520, n. 7.545, p. 45-50, 2015. DOI: 10.1038/nature14324

NOR, S. M. C. M.; SHAHARUDIN, S. M.; ISMAIL, S.; ZAINUDDIN, N. H.; TAN, M. L. A comparative study of diferente imputation methods for daily rainfall data in east-coast Peninsular Malaysia. **Bulletin of Electrical Engineering and Informatics**, v. 9, n. 2, p. 635-643, 2020. DOI: 10.11591/eei.v9i2.2090

OLIVEIRA, L. F. D. de.; FIOREZE, A. P.; MEDEIROS, A. M. M.; SILVA, M. A. S. Comparação de metodologias de preenchimento de falhas de séries históricas de precipitação pluvial anual. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 14, n. 11, p. 1186-1192, 2010. DOI: 10.1590/S1415-43662010001100008

OLIVEIRA, P. T. S.; WENDLAND, E.; NEARING, M. A. Rainfall erosivity in Brazil: A review. **Catena**, v. 100, p. 139-147, 2012. DOI: 10.1016/j.catena.2012.08.006

OLIVEIRA, P. T. S.; NEARING, M. A.; MORAN, M. S.; GOODRICH, D. C.; WENDLAND, E.; GUPTA, H. V. Trends in water balance components across the Brazilian Cerrado. **Water Resources Research**, v. 50, p. 7100-7114, 2014. DOI 10.1002/ 2013WR015202

OLIVEIRA, V. A. de; MELLO, C. R.; BESKOW, S.; VIOLA, M. R. Modeling the effects of climate change on hydrology and sediment load in a headwater basin in the Brazilian Cerrado biome. **Ecological Engineering**, v. 133, p. 20-31, 2019. DOI: 10.1016/j.ecoleng.2019.04.021

OVERBECK, G. E. et al. Conservation in Brazil needs to include non-forest ecosystems. **Diversity and distributions**, v. 21, n. 12, p. 1455-1460, 2015. DOI: 10.1111/ddi.12380

PANAGOS, P.; BORRELLI, P.; MEUSBURGER, K. et al. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. **Scientific Reports**, v. 7, n. 4175, p. 1-12, 2017. DOI: 10.1038/s41598-017-04282-8

POESEN, J. Soil erosion in the Anthropocene: Research needs. **Earth Surface Processes and Landforms**, v. 43, p. 64-84, 2017. DOI: 10.1002/esp.4250

PRS - Projeto Rural Sustentável Cerrado. **Sobre o Projeto**. 2021. Disponível em: < https://www.ruralsustentavel.org/>. Acesso em: 05 de set. de 2021.

RIQUETTI, N. B.; MELLO, C. R.; BESKOW, S.; VIOLA, M. R. Rainfall erosivity in South America: Current patterns and future perspectives. **Science of The Total Environment**, v. 724, p. 1-14, 2020. DOI: 10.1016/j.scitotenv.2020.138315

SHIN, J.; KIM, T.; HEO, J.; LEE, J. Spatial and temporal variations in rainfall erosivity and erosivity density in South Korea. **Catena**, v. 176, p. 125-144, 2019. DOI: 10.1016/j.catena.2019.01.005

SILVA, M. L. N.; FREITAS, P. L. de; BLANCANEAUX, P.; CURI, N. Índices de erosividade das chuvas da região de Goiânia, GO. **Pesquisa Agropecuária Brasileira**, v. 32, n. 10, p. 977-985, 1997.

SILVA, M. A. D.; SILVA, M. L. N.; CURI, N.; SANTOS, G. R. D.; MARQUES, J. J. G. D. S.; MENEZES, M. D. D.; LEITE, F. P. Avaliação e espacialização da erosividade da chuva no Vale do Rio Doce, região Centro-Leste do Estado de Minas Gerais. **Revista brasileira de ciência do solo**, v. 34, p. 1029-1039, 2010.

SOUZA, A. P.; SILVA, A. C. D.; TANAKA, A. A.; ULIANA, E. M.; ALMEIDA, F. T. D.; KLAR, A. E.; GOMES, A. W. A. Global radiation by simplified models for the state of Mato Grosso, Brazil. **Pesquisa Agropecuária Brasileira**, v. 52, n. 4, p. 215-227, 2017. DOI: 10.1590/S0100-204X2017000400001

TALCHABHADEL, R.; NAKAGAWA, H.; KAWAIKE, K.; PRAJAPATI, R. Evaluating the rainfall erosivity (R-factor) from daily rainfall data: an application for assessing climate change impact on soil loss in Westrapti River basin, Nepal. **Modeling Earth Systems and Environment**, v. 6, p. 1741-1762, 2020. DOI: 10.1007/s40808-020-00787-w

UYANıK, G. K.; GÜLER, N. A study on multiple linear regression analysis. **Procedia - Social and Behavioral Sciences**, v. 106, n. 2, p. 234-240, 2013. DOI:10.1016/j.sbspro.2013.12.027

WILLMOTT, C. J. On the validation of models. **Physical geography**, v. 2, n. 2, p. 184-194, 1981. DOI: 10.1080/02723646.1981.10642213

WISCHMEIER W. H. A rainfall erosion index for a universal soil-loss equation. **Soil Science Society of America Journal**, v. 23, n. 3, p. 246-249, 1959.

WISCHMEIER, W. H.; SMITH, D. D. **Predicting rainfall erosion losses**: a guide to conservation planning. Washington, DC: USDA, 1978.

WMO_World Meteorological Organization. **Guide to Meteorological Instruments and Methods of Observation**. n.08 Geneva: WMO, 2014. Disponível em: < http://www.posmet.ufv.br/wp-content/uploads/2016/09/MET-474-WMO-Guide.pdf>.

ZHU, D.; XIONG, K.; XIAO, H.; GU, X. Variation characteristics of rainfall erosivity in Guizhou Province and the correlation with the El Niño Southern Oscillation. **Science of The Total Environment**, v. 691, p. 835-847, 2019. DOI: 10.1016/j.scitotenv.2019.07.150