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EVALUATION OF METHODS FOR EROSION ESTIMATION USING GEOPROCESSING IN A MICROBASIN

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ABSTRACT

Erosion represents a crucial challenge for sustainable land use planning, especially with increasing agricultural activity and changes in production methods. This process leads to higher susceptibility to soil erosion, resulting in productivity losses and environmental degradation. Therefore, assessment methods are essential. This study compares the Universal Soil Loss Equation (USLE) with the Embrapa Erosion Susceptibility Map, utilizing geospatial data and applying it at different watershed planning scales. The objective is to assess and validate these methodologies, using satellite imagery to identify advanced erosive processes such as gullies.

The results indicate that the Susceptibility Map showed better correspondence with gully areas, while the USLE had some discrepancies, possibly due to its higher spatial resolution. However, it emphasizes the importance of on-site verification through field visits to complement model analyses.

KEYWORDS: Soil erosion, Geoprocessing, Universal Soil Loss Equation, Erosion Susceptibility Map, Satellite images.

AVALIAÇÃO DE MÉTODOS PARA ESTIMATIVA DA EROSÃO UTILIZANDO GEOPROCESSAMENTO EM MICROBACIA

RESUMO

A erosão representa um desafio crucial para o planejamento sustentável do uso do solo, especialmente com o aumento da atividade agrícola e mudanças nos métodos de produção. Isso leva a uma maior suscetibilidade à erosão do solo, resultando em perdas de produtividade e degradação ambiental. Portanto, métodos de avaliação são fundamentais. Este estudo compara a Equação Universal de Perda de Solo (USLE) com o Mapa de Suscetibilidade à Erosão da Embrapa, ambos usando dados geoespaciais e aplicáveis em diferentes escalas de planejamento de bacias hidrográficas. O objetivo é avaliar e validar essas metodologias, usando imagens de satélite para identificar processos erosivos avançados, como voçorocas.

Os resultados indicam que o Mapa de Suscetibilidade apresentou melhor correspondência com áreas de voçorocas, enquanto a USLE teve algumas discrepâncias, possivelmente devido à sua resolução espacial mais alta. No entanto, enfatiza-se a importância de verificar as condições no local por meio de visitas de campo para complementar as análises dos modelos.

Palavras chave: Erosão do solo, Geoprocessamento, Equação Universal de Perda de Solo, Mapa de Suscetibilidade à Erosão, Imagens de satélite

1 INTRODUCTION

An analysis of erosive processes is essential for proper territorial planning. Identifying vulnerabilities and challenges in the planning process is crucial to ensure that future initiatives are economically and environmentally sustainable in the long term. The intensive use of land, coupled with the development of agricultural and livestock practices, and changes in production methods, increases the susceptibility of the terrain to erosive processes. These erosive processes consequently lead to the loss of crop productivity, vegetation cover, sedimentation of water bodies, and the infeasibility of occupying territories during advanced erosive processes, such as gullies.

Models have been developed that diagnose areas based on georeferenced information related to the region's characteristics to assess the probability of erosive processes occurring in areas of interest for conservation. Cook (1936) was one of the first to formulate an erosion model, considering soil erodibility, rainfall erosivity, and vegetation cover factors. One of the most commonly used methodologies is the Universal Soil Loss Equation (USLE), developed by the U.S. Department of Agriculture (USDA) in 1954, which is applied through interpolations of various thematic data and widely used in soil loss studies. Another possibility for assessing erosion using geoprocessing is through the erosion susceptibility map generated by Embrapa Solos in 2020.

Methodologies for estimating erosion using geoprocessing enable assessments that would not be possible without on-site surveys. Both methodologies utilize readily available data acquired from traditional national geographic databases, allowing their application at different scales, thus becoming a valuable tool for territorial management of watersheds.

This study aims to compare the results of applying these methodologies and validate them using satellite images that depict advanced erosive processes in the Pará River watershed in Minas Gerais. The field survey was conducted as part of the Environmental Conservation and Water Production Program of the Pará River Basin Committee, contracted by the Peixe Vivo Agency in 2022, and carried out by the Água e Solo Estudos e Projetos company.

2 METHODOLOGY

2.1 Study area

The study area is located in the city of Carmo do Cajuru, in Minas Gerais, with the microbasin of Ribeirão do Sapé situated within the Pará River watershed. The microbasin covers an area of 2,600 hectares, with its main river, Ribeirão do Sapé, flowing into the artificial reservoir of Carmo do Cajuru, built for hydroelectric power generation, forming the largest artificial lake in the Central-West region of Minas Gerais. Figure 1 shows the location of the study area.

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ISSN 1807 - 1600

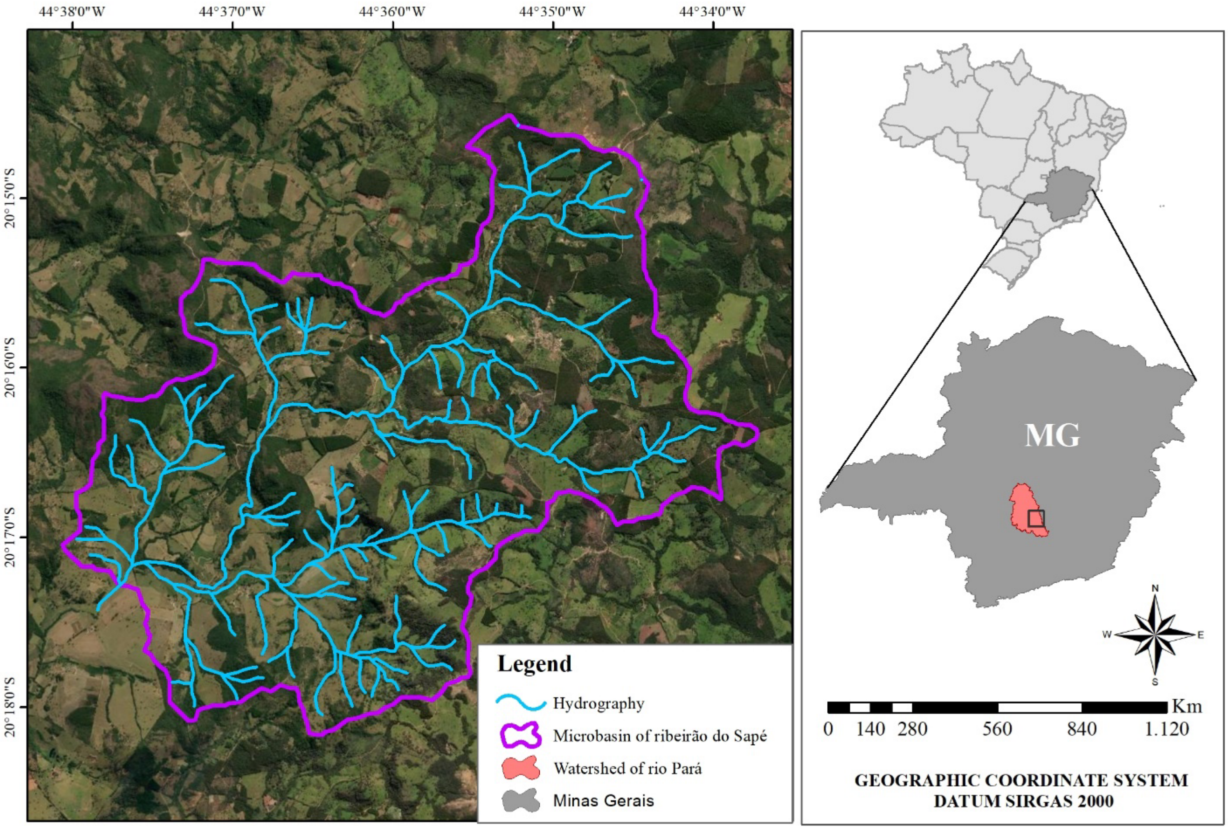

Figure 1: Location of the study area.

2.2 USLE

The USLE constitutes an empirical model created to estimate the average annual soil loss due to sheet erosion, providing crucial information for developing urban and environmental planning for watershed management plans (Silva, 2009). The USLE equation considers both natural and anthropogenic factors, which can be estimated and specialized in a Geographic Information System (GIS) environment, enabling optimization of data interpolation and more precise spatial results. Reference data, such as erodibility, were obtained from studies in regions with similar characteristics to the study area. The USLE soil loss equation is presented below. After introducing the equation, the environmental factors that compose it will be discussed individually.

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

A = Soil loss (ton/ha/year);
R = Erosivity, rainfall erosion index (MJmm/ha/year);
K = Soil erodibility, in ton ha.h/ha. (MJmm);
L = Length of slope (m);
S = Slope gradient (%);
C = Dimensionless, related to surface cover or land use/management;
P = Dimensionless, referring to conservation practices.

3 RESULTS AND DISCUSSIONS

3.1 USLE

This section will present the results of applying the USLE and the Embrapa Erosion Susceptibility Map. For the USLE, each factor that makes up the soil loss equation will be discussed, starting with the rainfall erosivity factor.

The rainfall erosivity factor (R) expresses the ability of rainfall in a particular location to erode unprotected soil (WISCHMEIER, 1959). Therefore, quantifying this factor is essential in determining suitable soil uses and management practices (Bazzano et al., 2010). Evaluating the evolution of erosivity throughout the year is also an exciting tool for crop planning. By identifying the months with the highest rainfall erosivity, farmers can plan the most effective application of conservation practices during these critical periods (Bertoni and Lombardi Neto, 1990).

Precipitation data were obtained from the National Water and Sanitation Agency (ANA) database. After evaluating the available data, 12 rainfall stations around the microbasin were selected for data interpolation. The historical series considered included the period from 2000 to 2021. Thus, the estimate of the monthly erosivity index was obtained and calculated using the equation developed by Val (1986) for the city of Lavras (MG):

$$R = 125{,}92 \times \left(\frac{p^2}{P}\right)^{0{,}603} \qquad (2)$$

R = Rainfall erosivity factor ($MJ.ha^{-1}.\ mm.h^{-1}$.ano^{-1});
Pm = Monthly average precipitation (mm);
Pa = Annual total precipitation (mm).

Several equations estimate rainfall erosivity. For this study, an equation developed in a region with similar characteristics to the evaluated microbasin was selected. Figure 2 presents the map generated after interpolating rainfall erosivity in the microbasin.

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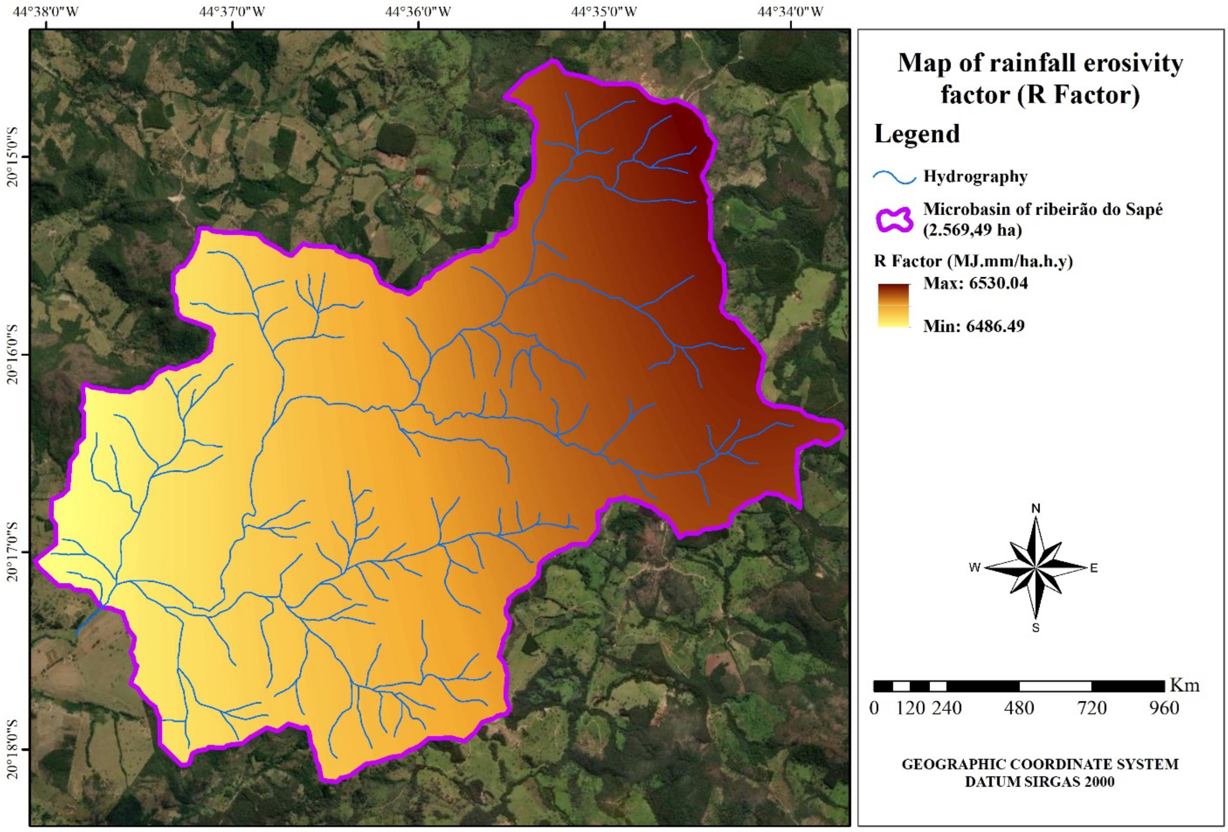

Figure 2: Rainfall erosivity factor (R).

The calculation of the topographic factor (LS) allows for the analysis of water erosion in an area, taking into account the distance over which surface runoff occurs (L) and the slope of the terrain (S). Thus, experimentally, this factor expresses the relationship between soil loss per unit area on any slope compared to a plot of 22 meters in length and a 9% slope (Wischmeier & Smith, 1978). Therefore, the longer and steeper the slope, the greater the erosion. The methodology proposed by MOORE & BURCH (1986) was used to determine the topographic factor of the microbasin, which utilizes the Digital Elevation Model (DEM) for calculating accumulated flow and slope. The DEM used has a resolution of 12.5 meters, derived from reprocessing the 30-meter resolution Digital Elevation Model available through SRTM, as per the equation below.

$$LS = \left(\frac{FA \times CS}{22,13}\right)^{0.4} \times \left(\frac{sen\ (S)}{0,0896}\right)^{0.3} \quad (3)$$

FA = accumulated flow;
CS = cell size of the DEM (m) (flow length);
S = slope (degrees).

Figure 3 represents the result generated for the study area. The generated values are directly associated with the topography of the area.

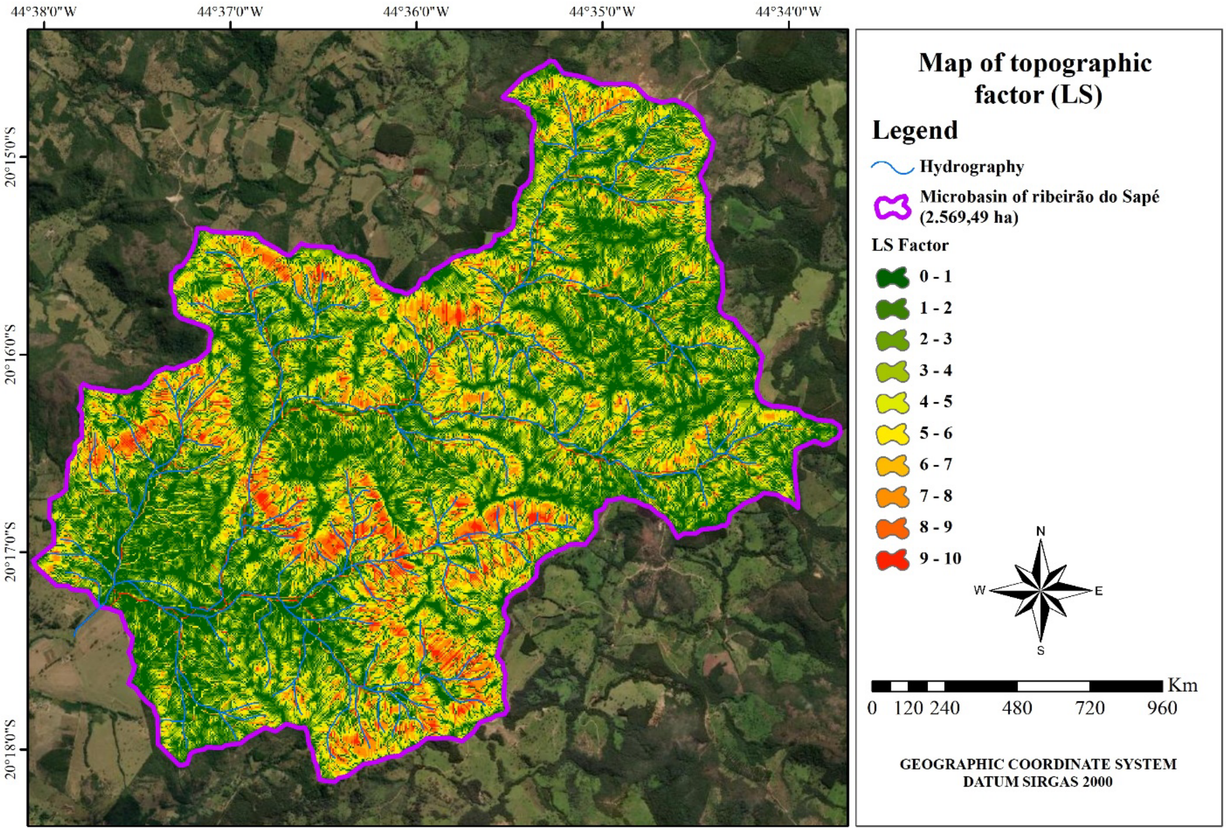

Figure 3: Topographic factor (LS).

According to Carvalho et al. (2009), the physical, chemical, and biological properties intrinsic to each soil type characterize different behaviors related to soil loss through water erosion. Soil erodibility, represented in the USLE as factor K, is related to properties such as texture, organic matter content, structure, and permeability. Soils characterized by higher erodibility values experience more significant soil loss through erosive processes, indicating a reduced ability to control water infiltration into the soil, lower resistance to transport by surface runoff, and greater disintegration due to the impact of raindrops.

Table 1 presents the soil classes found in the study area. To assign erodibility values to the soil types in the area, literature sources estimating this factor based on experiments were considered. A value of K equal to 0.0171 (Low) was assigned to the Dystrophic Red-Yellow Latosol (LVA), a value of K equal to 0.0338 (High) was assigned to the Dystrophic Red-Yellow Argisol (PVA), and a value of K equal to 0.0255 (Medium) was defined for the Typical Eutrophic Litholic Neosol (R). Figure 4 shows the spatial distribution of the K factor in the evaluated microbasin.

Table 1: Factor K.

Soil	Factor K	Percentage of the microbasin	Erodibility risk class	Reference
LVA	0.071	25.29%	Low	Reatlo el al, 2000
PVA	0.0338	45.86%	High	Chaves. 1994
R	0.0255	28.85%	Medium	Francisco, 2010

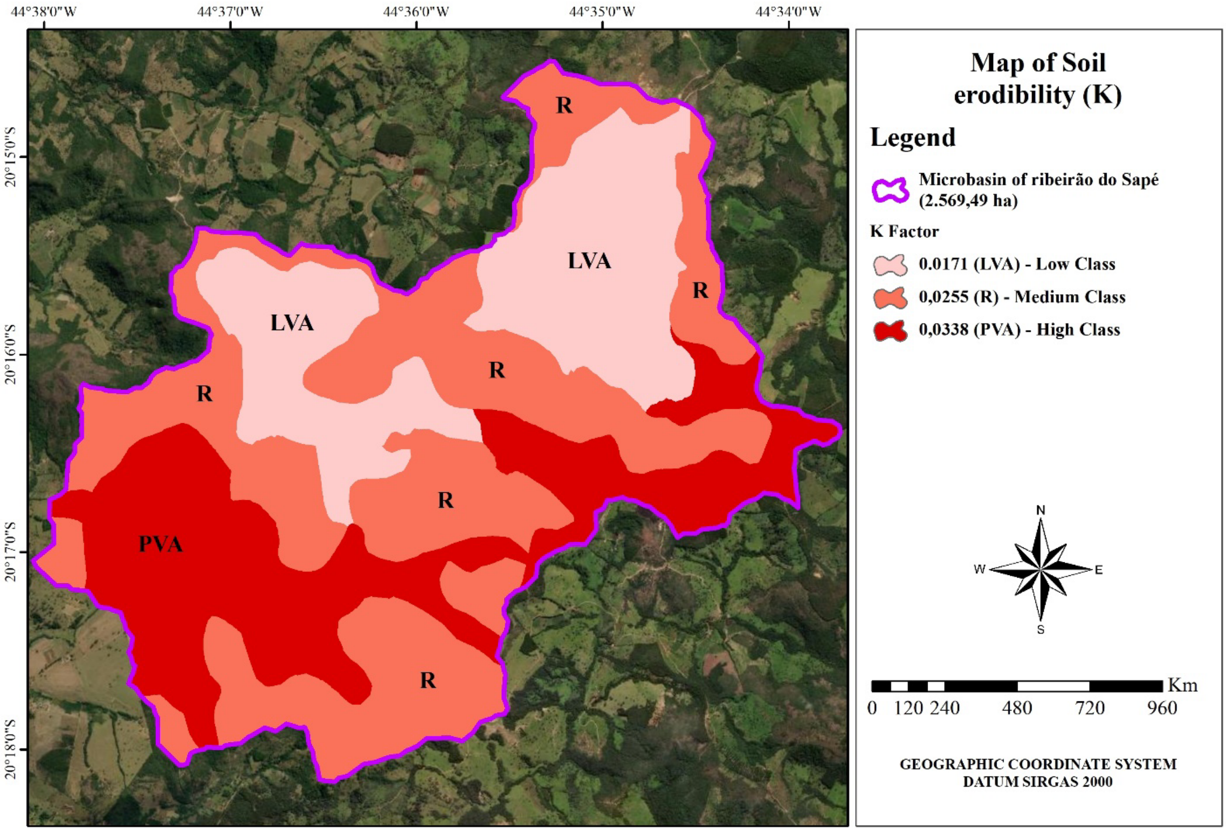

Figure 4: Soil erodibility (K).

The soil management and land cover factors express the relationship between soil loss and the management in a particular area. Different land uses and vegetation cover correspond to different soil loss behaviors, making areas more or less vulnerable to water erosion (MOTA, 2021). It is considered that land uses with a lower tendency for soil loss (lower value for factor C) are found when there are no processes of particle disaggregation and solid material transport, such as in watercourses and urban areas. According to Guadagnin et al. (2005), the highest values of factor C are associated with classes with little or no soil cover, characterizing high susceptibility to erosion. The maximum and minimum values range from 1 to 0. Table 2 presents the values of C found for the microbasin, while Figure 5 shows the geospatial results.

Satellite images were used to obtain the land use map. The choice of satellite image for processing considers spatial and temporal resolution. After evaluating the available images, we opted for the CBERS-4A satellite images dated June 2022. After composing the bands to generate the true-color image, Pansharpening processing was performed to increase the spatial resolution of the panchromatic band from 8m to 2m in the RGB (true-color) composition. Thus, the resulting image had a spatial resolution of 2m.A classification operation was performed using the processes satellite and geoprocessing tools to identify land use classes based on the coloration of the images, thereby generating the land use map for the microbasin with a 2m resolution, superior in quality to MapBiomas (30m), for example.

Table 2: Factor C.

Soil	Factor C	Reference
Urban Area	0	Stein et al. 1987

Soil	Factor C	Reference
Water Bodies	0	Stein et al. 1987
Native Vegetation	0.01	Beskow 2009
Pasture	0.025	Bertoni e Lonbardi Neto 2005
Field	0.042	Silva 2004
Silviculture	0.047	Silva el al. 2010
Agriculture	0.29	Beskow 2009
Exposed Soil	1	Stein et al. 1987

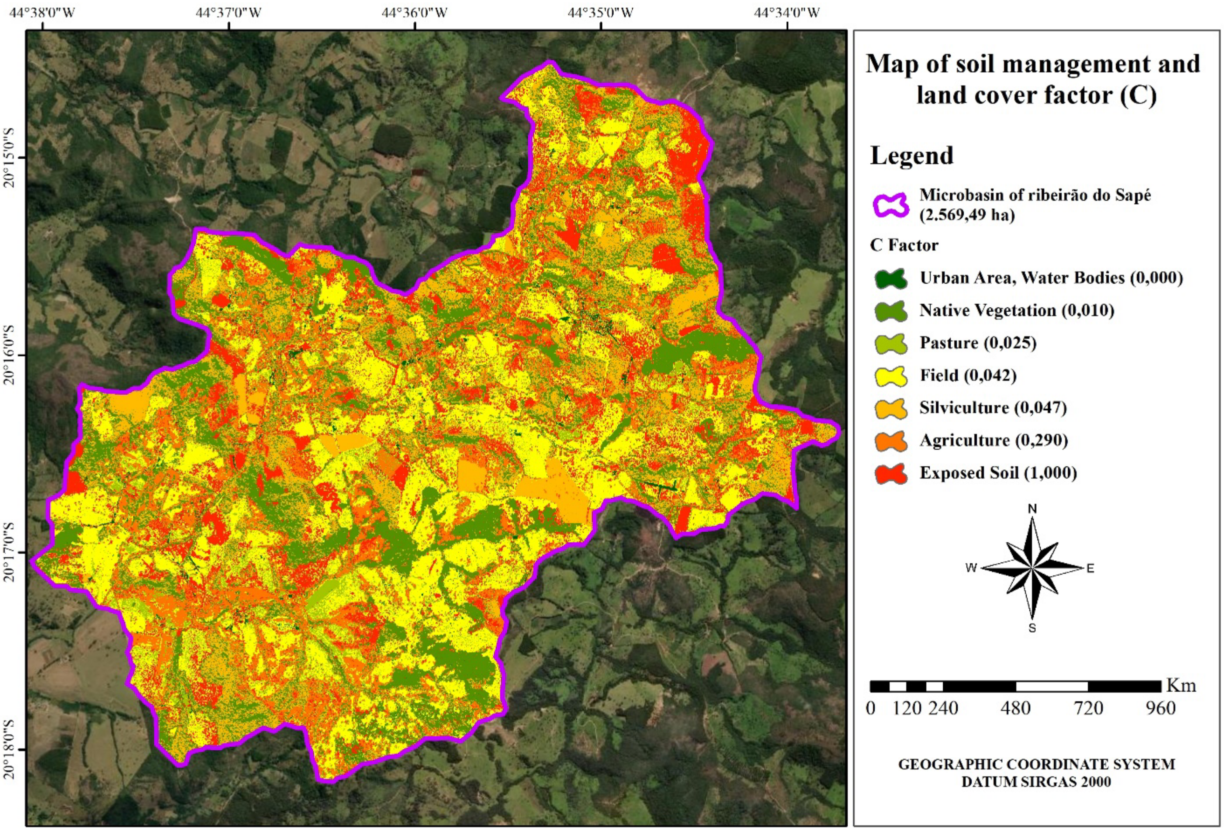

Figure 5: soil management and land cover factor (C).

Factor P relates the intensity of soil loss to conservation practices employed in the study area (Silva et al., 2010). Soil conservation practices reduce erosive processes and, consequently, soil loss values. The most common practices are contour planting, strip cropping, terracing, and weed control alternations. Bertoni and Lombardi Neto (1992) work with both factors separately: factor C as "land use and management" and factor P as "conservation practices" (MATA et al., 2007). However, for Wischmeier and Smith (1978), factors C and P are significantly related and should not be analyzed separately. The CP factor represents the combined effect of land cover and soil management variables. For the study area, the values for factor P were assumed to be 1.0 due to the lack of identified soil conservation practices, Beskow et al. (2009) adopted. No thematic map will be presented since it's a single value for the study area.

HOLOS
ISSN 1807 - 1600

3.2 Erosion Susceptibility Map (Embrapa, 2020)

In 2022, the Brazilian Agricultural Research Corporation (Embrapa), through its Embrapa Solos division, developed the Soil Erosion Susceptibility Map of Brazil at a 1:250,000 scale. The map classified areas based on their susceptibility to water erosion into five classes: Very Low, Low, Medium, High, and Very High. The following input data were used to create this map: (a) a Soil Erodibility Map of Brazil (Embrapa, 2020); (b) a Rainfall Erosivity Map of Brazil (Embrapa, 2020); and (c) a Digital Terrain Model with a 30-meter spatial resolution (SRTM/NASA). Figure 6 shows the map created for Brazil. This map is available for access on the Geoinfo platform, which contains geographic information generated by Embrapa.

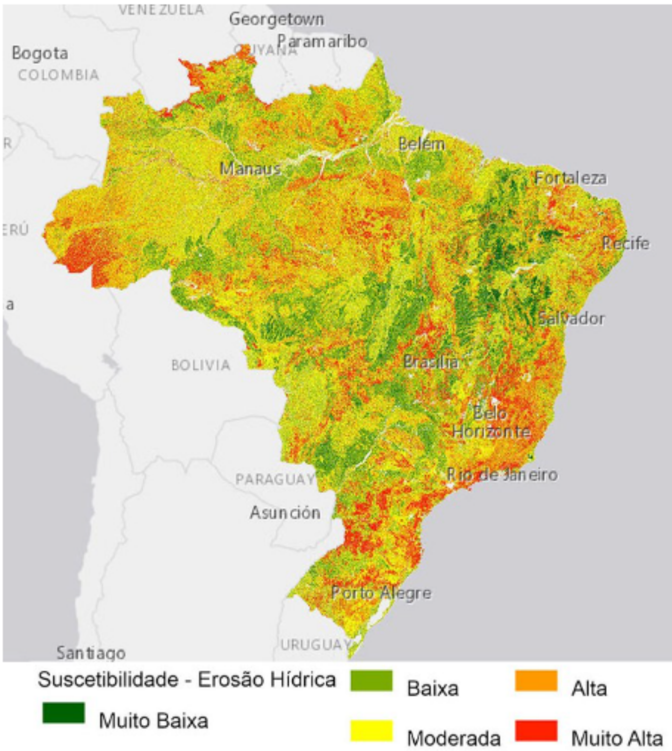

Figure 6: Map of Susceptibility to Water Erosion in Brazil.

The Rain Erosivity and Digital Terrain Model models were initially generated in raster format, while the Soil Erodibility model, originally in vector format, was converted to raster format. All models were processed in grids with 30x30m pixels. The processing was carried out on the Google Earth Engine platform. The method was developed by a team of researchers and analysts from Embrapa Solos (RJ), consisting of experts in soil science, agrometeorology, regional planning, and digital agriculture.

During the execution of the Soil and Water Conservation Program in the Pará River basin, field visits were conducted to identify issues related to the program's aspects. One of the problems identified was the presence of gullies in the microbasin. The visit took place in mid-2022. One of the three large gullies in the study area was identified during the survey. The visited gully covers an area of approximately 52,518.50 square meters and has a depth of over 30 meters.

3.3 Satellite images

Using satellite images, it is possible to identify two more gullies within the microbasin boundary. These gullies are already in an advanced stage of development with significant vegetation cover inside them. Analyzing the temporal evolution of the gullies, it is evident that the processes began before 2003, the year of the first available satellite image acquisition. Gully 1 has more vegetation cover than gullies 2 and 3, which may have undergone slope sliding processes, explaining the reduction in vegetation cover over the assessed period. Table 3 provides some information about the identified gullies that will be the subject of analysis in this study. Figure 7 shows the location of the gullies in the microbasin.

Table 3: Information of the identified gullies.

Identification	Location	Area of Extension
Voçoroca 1	20°16'22.45"S; 44°34'25.48"O	52,518.50 m²
Voçoroca 2	20°16'14.59"S; 44°35'22.84"O	9,121.31 m²
Voçoroca 3	20°15'52.90"S; 44°36'6.83"O	10,426.30 m²

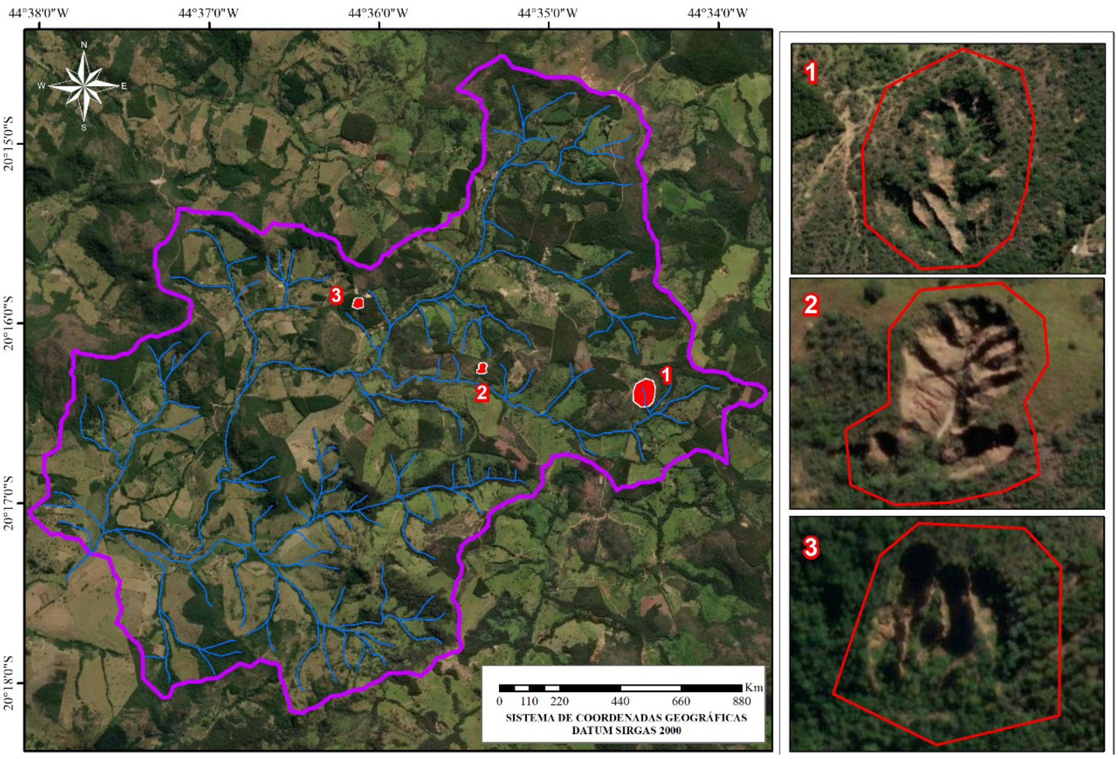

Figure 7: Location of the gullies.

Below, some photographs taken by the field inspection team are presented.

Figure 8: Gully 1 visited in the field.

The two erosion estimation methodologies, USLE and Embrapa Solos' susceptibility map, were compared to evaluate the results. As validation, the areas where the gullies were identified in satellite images were selected. The classes with the highest erosive potential (USLE) and the highest susceptibility to erosion (Embrapa) within the areas with identified gullies were considered for assessment. The following tables present the results found for each of the evaluated methodologies.

Figure 9 shows the map of susceptibility to water erosion in the study area. Figure 10 presents the results obtained by applying the USLE methodology in a GIS environment, using the factors presented in the previous section as a basis. A visible difference in information resolution is evident when analyzing the generated maps. The USLE map has a resolution of 2 meters, while the susceptibility to erosion map has a spatial resolution of 30 meters.

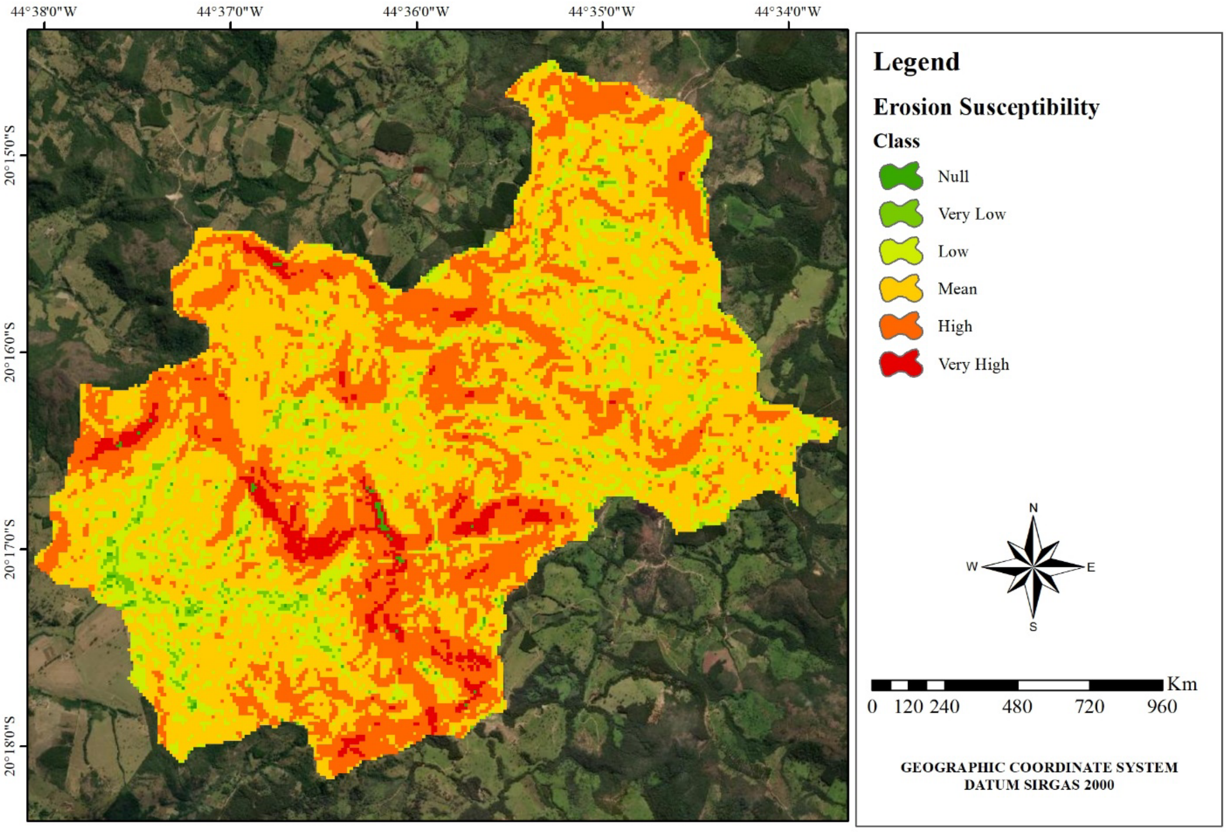

Figure 9: Susceptibility to erosion map (Embrapa Solos, 2020) of the study area.

Table 4: Results for Embrapa Solos' susceptibility map for erosion in the study area.

Gullies	Null	Very low	Low	Mean	High	Very High
1	0%	0%	8%	43%	47%	1%
2	0%	0%	0%	22%	78%	0%
3	0%	0%	0%	9%	91%	0%

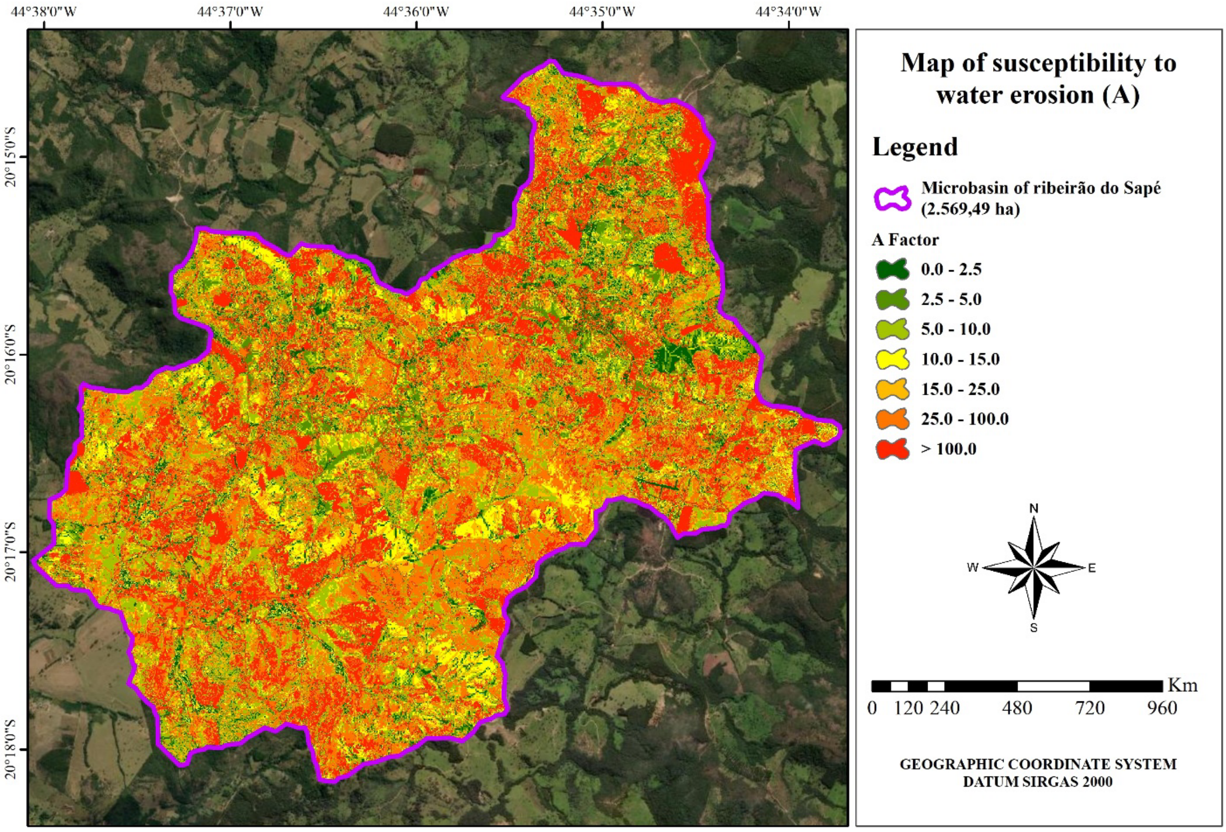

Figure 10: Soil loss map (USLE) of the study area.

Table 5: Results from the USLE in the study area.

Gullies	Mild	Mild to moderate	Moderate	Mean and High	High	Very High	Extremely high
1	6%	6%	18%	14%	5%	19%	32%
2	3%	1%	12%	7%	1%	11%	65%
3	2%	1%	26%	14%	1%	21%	34%

Table 6 shows the correspondence between the area where the three identified gullies exist in the microbasin and the classes of higher criticality. For the composition of the correspondence, the sum of the classes from moderate (USLE) to very high (USLE) or extremely high (USLE) was considered.

Table 6: Comparison of Results.

Gullies	Correspondence in the most critical classes	
	Susceptibility	USLE
1	92%	70%
2	100%	85%
3	100%	71%

Considering this evaluation, the susceptibility map showed better results. The fact that the USLE is at a spatial resolution of 2 meters makes some local results seem out of touch with reality.

Overall, it provides good results, but the methodology needs to be improved in detail. On the other hand, the Embrapa Solos map has a spatial resolution of 30 meters and, therefore, classified most areas in the same class precisely because there are few pixels within the gully areas. In the case of this study, the classification was more accurate. Still, if there were a single misclassification, the entire gully area could be wrongly classified, affecting the planning of soil conservation actions in the basin.

4 CONCLUSION

Considering the best results as those with higher correspondence with the areas where gullies exist, the Embrapa susceptibility map was more satisfactory than the application of USLE. However, it is worth noting that USLE provides good results at the scale used, with some outliers that may be due to scale effects in its analysis. It is always recommended to verify conditions in situ, i.e., through on-site visits.

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