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EVALUATION OF DIFFERENT METHODS OF ESTIMATION OF THE TOPOGRAPHIC FACTOR AND ITS INFLUENCE ON SOIL LOSS DISTRIBUTION IN THE JAÚ STREAM WATERSHED, IN APARECIDA D'OESTE – SP

* Mariana Barbosa de Carvalho [1]
Nelson Giovanini Junior [1]
César Gustavo da Rocha Lima [1]
José Augusto de Lollo [1]

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Abstract

Concern about the environment and the need for solutions to environmental problems are growing every day. Among the various types of research carried out in this field, the study of soil erosion is highlighted, especially the accelerated erosion. Several methods are used to evaluate the occurrence of erosion processes, and the parameters considered in each one of them can also be diverse, being both natural and anthropic. The Universal Soil Loss Equation (USLE) is one of the most widespread methodologies used in this research field. Among the six parameters considered in the USLE, there is the topographic factor (LS), which refers to the influence of relief on the occurrence and development of erosion processes, being this a relevant factor and which importance is already demonstrated. There are many ways to estimate topographic factor, and this work will analyze the distribution of soil loss in the Jaú Stream watershed, in Aparecida D'Oeste-SP, obtained through USLE, in view of these different estimation methods.

Keywords: erosion, GIS, topographic factor, USLE.

[1] Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista Júlio de Mesquita Filho, Brasil.
** Corresponding author:* Faculdade de Engenharia de Ilha Solteira, Universidade Estadual Paulista Júlio de Mesquita Filho, Alameda Bahia, 550 – Centro, Ilha Solteira, São Paulo. 15385-000. Brasil. Email: maa.carvalho@hotmail.com

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Introduction

Soil erosion is a phenomenon that can occur naturally, through slow and continuous processes of modification of the earth's crust - then being called geological erosion -, or have anthropic influence, with humans responsible for both the intensification of existing erosive processes and the generation of new ones (Zachar, 1982).

The accelerated erosion, besides being a form of environmental degradation by itself, also causes other types of problems, such as the decline of food production, the desertification of areas, the silting of rivers, among others. Bertoni and Lombardi Neto (1999) even claim that soil erosion makes the land gradually uninhabitable, whatever its cause.

The development of erosive processes can be determined either by natural factors such as soil pedology, climate and relief, or by anthropic factors such as soil occupation and management techniques.

According to Salomão (1999), among the parameters most used in the study of erosion susceptibility are those related to rainfall, vegetation cover, topography, and soil types. These parameters and the way they are used vary according to the adopted study methodology. Among the methods used to assess the occurrence of erosion processes there are SWAT (Furl *et al.*, 2015; Halecki *et al*., 2018; Zhang *et al*., 2017), WEPP (Nearing *et al*., 1989; Anache *et al*., 2018; Brooks *et al*., 2016), LISEM (Starkloff and Solte, 2014; Gomes *et al*., 2008), USLE (Beskow *et al*., 2009; Medeiros *et al*., 2016; Ozcan *et al*., 2008), VNE (Crepani *et al*., 2001; Ribeiro and Campos, 2007), multicriteria models (Ameri *et al*., 2018; Nekhay *et al*., 2009; Martini *et al*., 2006), among others.

The Universal Soil Loss Equation - or USLE - is one of the most widespread empirical methodologies used in the field of erosion potential study, having been developed by Wischmeier and Smith (1978). This method consists in calculating the average rate of soil loss due to surface runoff over long periods in a specific area from the following factors: rainfall erosivity factor (R), soil erodibility factor (K), topographic factor (LS), land cover and management factor (C), and support practices factor (P).

In addition, Silva *et al*. (2016) observed in their study (in the Sapé sub-basin, in the State of Minas Gerais, using the AHP method) that the sites that presented high susceptibility to erosion were those with high slopes and geological basis favorable to its appearance, highlighting the slope factor. Also, Pham *et al*. (2018), using USLE in a watershed in Vietnam, verified that the factor of greatest influence in the estimation of the erosion rate was the topographic factor (LS). Therefore, in spite of the different forms of inclusion of the topography factor in the study methodologies, the great relevance of this parameter is evident.

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Although the original work of Wischmeier and Smith (1978) indicates how each factor should be estimated, there are several adaptations of the USLE to make it suitable to different scenarios and availability of data. These adjustments are very frequent, usually having in common the structure of the equation used, but the ways of obtaining the values for each parameter can vary, with several studies focused on the estimation of a single factor (Lima *et al*., 2016; Machado *et al*., 2017; Oliveira *et al*., 2012).

Thus, although USLE was developed at first to be used in places with little or no slope, as agricultural areas of gentle relief, due to the adaptations it could be successfully applied in much more complex topographies, being used until nowadays (Desmet and Govers, 1996; Medeiros *et al*., 2016).

There are several studies aimed at estimating the topographic factor in different ways. Ruthes *et al*. (2012) suggest, for example, a simplified way of obtaining slope-steepness and slope-length factors separately and then combine them according to the adaptation proposed by Bertoni and Lombardi Neto (1999).

Other authors recommend automated calculations, such as Moore *et al*. (1991), whose work points to the deficiency of many hydrological models regarding their inability to consider the real (three-dimensional) effects of relief in surface runoff, which leads to unrealistic simplifications.

Thus, this work will analyze the soil loss distribution in the Jaú Stream watershed, in Aparecida D'Oeste-SP, obtained through the USLE, in view of different methods of estimation of the topographic factor. Through these spatial models, the areas within the basin with greater and lesser susceptibility to erosion can be identified, and this distribution can then be compared to records of erosion processes to verify the applicability of the methods studied. All data modeling will be done using geographic information systems (GIS), which not only simplify the modeling process, but also facilitate spatial and comparative analysis.

Methodology

Characterization of the study area

This work is based on the Jaú Stream watershed, located in the northwest region of the State of São Paulo, within the limits of the municipality of Aparecida D'Oeste, whose main economic activities are diversified agricultural practices and extensive livestock farming (CBH-SJD, 2018). The cultivation of sugarcane and citrus fruits, as well as cattle breeding, stand out in the microbasin.

The Jaú stream basin is approximately 82.64 km², located between the geographic coordinates 20°34'42" S - 50° 59'58" W and 20°23'11" S - 50°49'33" W, according to Figure 1. The climate of

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the region is tropical with dry winter season and rainy summer (Aw, according to the classification of Köppen), and the average annual precipitation for the municipality is 1247.7 mm / year, according to the Center for Meteorological and Climatic Research Applied to Agriculture - CEPAGRI (2018). In addition, according to the Pedological Map of the State of São Paulo (Rossi, 2017), the study basin is composed of Red-Yellow Acrisols, Arenosols, and Gleysols.

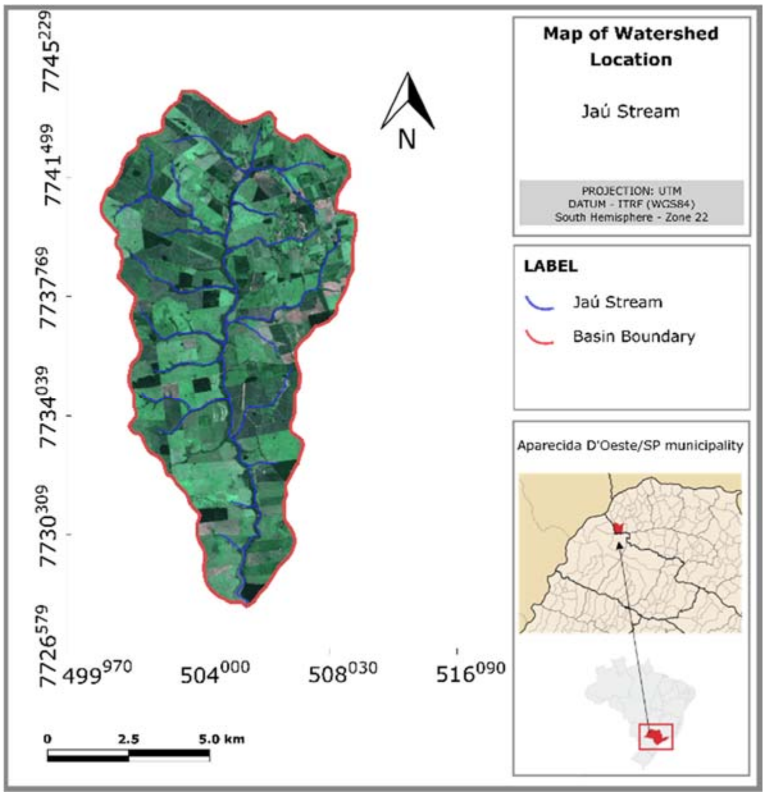

Figure 1. Map of Jaú Stream watershed location.

Application of the Universal Soil Loss Equation (USLE)

The Universal Soil Loss Equation can be expressed as follows:

$$A = R \times K \times LS \times C \times P \qquad \textbf{(Equation 1)}$$

Where

A: soil loss per unit area (ton.ha^{-1}.year^{-1});

R: rainfall erosivity factor (MJ.mm.ha^{-1}.h^{-1}.year^{-1});

K: soil erodibility factor (ton.h.MJ^{-1}.mm^{-1});

LS: topographic factor (dimensionless);

C: land cover and management factor (dimensionless);

P: support practices factor (dimensionless).

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Erosivity factor

The erosivity values were obtained through the netErosividade SP program. Based on data from rainfall stations distributed by the state and an artificial neural network, this program estimates rainfall erosivity values for any location in the state of São Paulo using latitude, longitude and altitude data. The calculation of erosivity by the program is based on annual average precipitation data from 1961 to 1990 using the equation proposed by Lombardi Neto and Mondenhauer (1992) for sites where there is a rainfall station, and the results in the other locations are estimated using interpolation and the developed artificial neural network (Moreira *et al*., 2006).

Soil Erodibility factor

The values used for soil erodibility were based on the work of Lima *et al*. (2016), in which soil samples were collected and analyzed in a certain area of the São José dos Dourados basin in which the study basin is inserted. The erodibility was estimated indirectly from the Bouyoucos (1935) methodology, which uses only the percentages of sand, clay and silt in the soil.

Land Cover and Management factor

The land cover and management factor (C) refers to the relation between soil loss under certain specific coverage conditions and the one expected for an exposed soil with no protection, and it is dimensionless (Wischmeier and Smith, 1978).

The map of land cover was elaborated from Sentinel-2 satellite images, dated 2/22/2018. A pixel-supervised classification (MAXVER) was used, using a color composition by combining the bands 03 (B), 04 (G) and 08 (R) - denominated false color - with resolution of 10 meters. Subsequently, a post-classification process was carried out to reduce possible local distortions of the classification process.

Due to the similarity between the types of use and coverage and the characteristics of the study regions, the value attributed to each category was taken from the work of Silva *et al*. (2010), except for wetland vegetation, whose value was taken from Medeiros *et al*. (2016).

Topographic Factor

The topographic factor (LS) is the influence of the relief in the erosive process and is formed by the combination of the factors slope-length (L), which consists of the distance traveled by the raindrop from the moment it reaches the ground to the water body, and slope-steepness (S). Both components are determinant for the volume and velocity of the runoff, and thus for the erosive capacity of the runoff, which can be understood as the kinetic energy resulting of the flow.

The factors can be calculated individually using a digital elevation model (MDE) and an area drainage map, or a software can be used to automatically calculate the LS factor by insertion of the same data sets. In the present work, these two methodologies were used.

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The calculation of the slope-length at each place was made based on the distance map between the watercourses and the topographic dividers, using the Spring software tool of the same name, so that the watercourses had zero value and the dividers had the maximum distance value. The location of the water dividers was based on a simplification in which the average distance between watercourses was considered, since to identify their exact location would be necessary a manual insertion (which would be time consuming) or the use of more complex operations, which are not the focus of the work.

The slope-steepness was obtained through SRTM data from the Topodata Project (INPE, 2018), and both data – L and S factors - were combined through a LEGAL using Equation 2 (Bertoni and Lombardi Neto, 1999) to be
later inserted in the USLE.

$$LS= 0.00984\ L^{0.63}\ S^{1.18}$$ **(Equation 2)**

Where:
L: slope-length in meters
S: slope-steepness in %

For the direct calculation of the LS factor, the SAGA software (Conrad *et al*., 2015) was used, in which the digital elevation model (altimetry map) inserted was also obtained from SRTM data from the Topodata Project (INPE, 2018). Among the possible methodologies available in the software for calculating this factor, the one developed by Bohner and Selige (2006) was selected because it is the most up to date.

Support Practices factor

It was not possible to identify the specific practices of each site, especially due to the size of the study area and its heterogeneity. However, it was observed from the visual analysis of satellite images that most of the properties have contour farming, regardless of the land use and cover class.

Thus, the approximation suggested by Silva *et al*. (2010) was tested, in which the factor P is calculated based on the terrain slope for areas with contour farming. According the authors work, for slope-steepnesses lower than 0.5% was assigned the value P = 0.6, for slopes greater than 20% was assigned the value P = 1, and for slopes between 0.5% and 20 % the Equation 3 was used.

$$P=0.69947 - 0.08911S + 0.01184S^2 - 0.000335S^3$$ **(Equation 3)**

Where:
S: Slope-steepness in %

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<u>*Comparison to records of erosion occurences*</u>
After the development of erosion potential maps generated from the two methods of estimation applied, the results were compared with records of erosive features in the study area.

Two sources were used to obtain this data, one of them being the Urban and Rural Erosive Feature Map of the São José dos Dourados River Basin, developed by CPTI and IPT (2008). The second way of obtaining the erosion data was through the analysis of high resolution satellite images through the program Google Earth Pro (Google, 2018) and visual identification of erosive features.

Results and discussion

In order to generate the map of erosivity using the netErosividade software, 50 random spots were selected within the basin and, based on their geographic coordinates and altitude, the values of erosivity were found. Then, the data were interpolated to obtain the erosivity map, shown in Figure 2A. In regard of the distribution of erodibility, based on the spatial location of the places of sample collection from the Lima *et al*. (2016) work and through the geostatistical methods of Kriging and Cokriging, the soil erodibility map for the Jaú watershed was elaborated, according to Figure 2B.

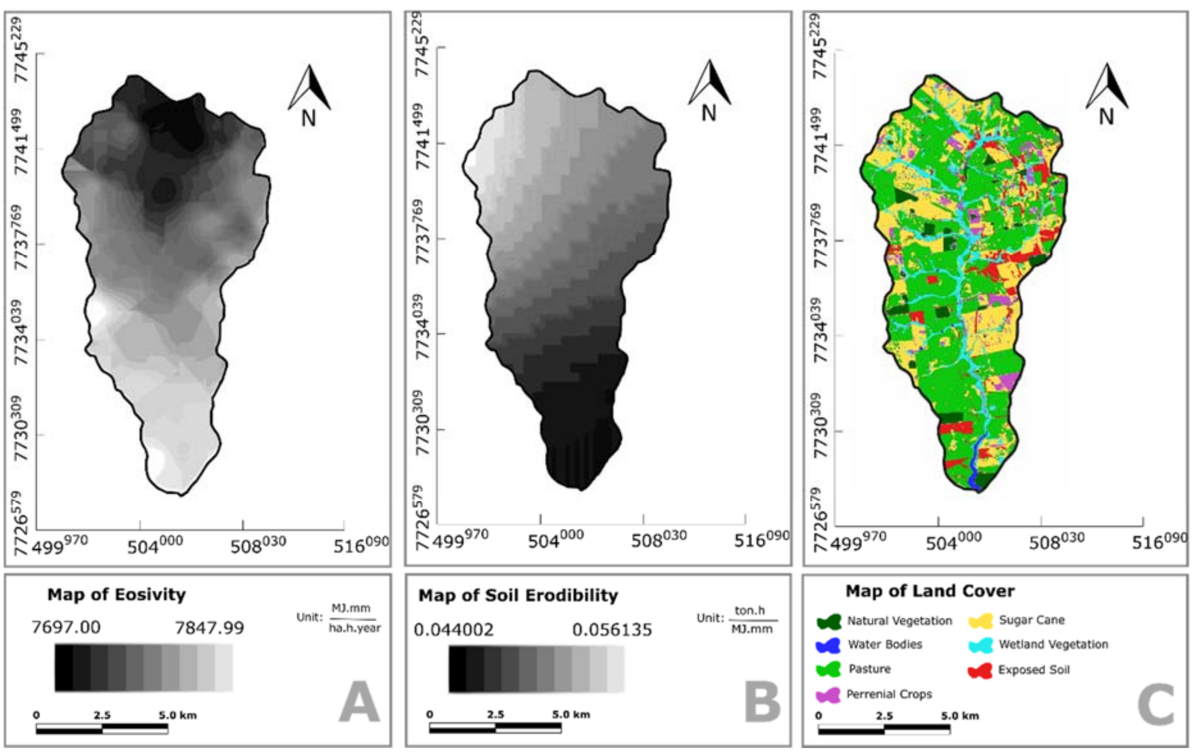

Figure 2. Maps of the factors Erosivity (A), Soil Erodibility (B) and Land Cover and Management (C) used in USLE.

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The map of land cover, generated through working with satellite imagery of the basin, as described in the methodology, is presented on Figure 2C, and the values used for each class in order to obtain the land cover and management factor are given in Table 1.

Table 1. Classes of land cover and management factor.

Classes of land cover	Factor C
Natural Vegetation	0.0004
Pasture	0.05
Sugar Cane	0.1124
Perennial Crops	0.135
Wetland vegetation	0.0001
Water Bodies	0
Esposed Soil	1

Figure 3 shows the LS factor distributions from the two calculation methods tested, with Figure 3A referring to the calculation of L and S factors individually and then combined through Equation 2 (a method named as usual or simplified in this work), and Figure 3B referring to the direct estimation of the LS factor through the SAGA software.

A major difference between the two estimation methods is that the former considers only the main drainage network, with representation in the database, while the second method does not require data entry for drainage, using the digital terrain elevation model itself to estimate the location of valleys and hill tops, where the watercourse beds and topographic dividers would be situated, respectively.

This second form of estimation, using the SAGA software, is more accurate, since it considers the particularities of the terrain and has no operator interference, not being subject, for example, to errors such as an outdated drainage network. Nonetheless, this also generates a large local variation, which can be interesting depending on the study interest, but for a general assessment of the basin and identifying areas most susceptible to the occurrence of erosion, this kind of representation may not be the most appropriate.

At first it can already be seen the great difference between the two maps in Figure 4. There is a predominance of bluish-green tones on Map A, with a preponderance of soil losses between 10 and 50 $ton.ha^{-1}year^{-1}$.

It is noted that within the category of lower soil loss are the areas occupied by natural vegetation and most of the main bed of the Jaú stream, covered by wetland vegetation, with an expressive

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percentage (more than 10%) of the basin exhibiting soil losses between 0 and 1 ton.ha^{-1}year^{-1}. On the other hand, the areas with the most extreme soil losses are those that do not have any type of vegetation cover (exposed soil), which indicates the influence of the land cover and management factor.

Additionally, in Figure 4A can be identified regions with a certain concentration of areas with high soil losses located in the northwest, northeast, east and south of the basin. It is also noticed that these areas with high soil loss results match with those that presented the highest LS values in Figure 3, which demonstrate the relevance of this factor for the study.

Meanwhile, the map produced from the LS factor of the SAGA program shows the predominance of the extreme classes of soil loss. It is possible to see that the areas with the lowest soil loss are those covered by natural vegetation and vegetation of the wetlands (main stream bed), but due to the homogeneity of reddish tones, it is difficult to identify the regions of the basin with the highest soil losses.

This condition of predominance of extreme soil losses is also observed in Table 2, in which it is noticed that more than 50% of the area of the basin is in regions with soil loss above 300 tons.ha^{-1}year^{-1}.

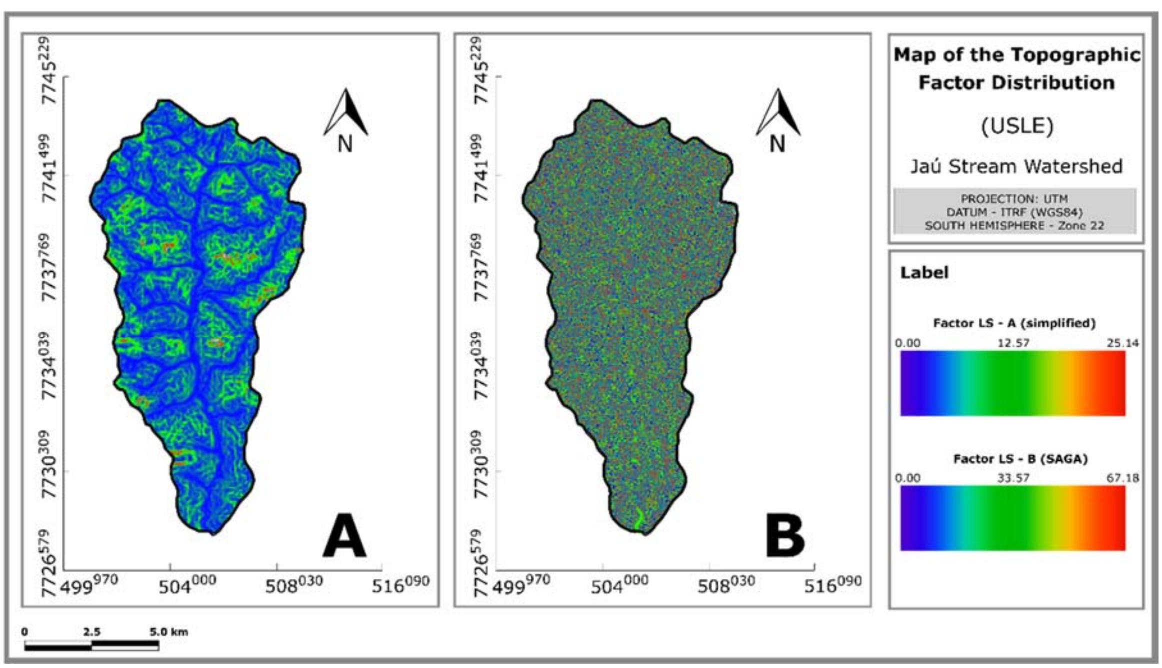

Figure 3. LS factor distribution for the Jaú Stream Watershed through the simplified method (Fig. A) and the SAGA software (Fig. B).

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After that, two combinations of USLE were performed, varying only the LS factor while all other factors in the equation were maintained the same. Figure 4 displays the soil loss maps generated from the two LS factor estimation methods studied: the simplified (Figure 4A) and the direct (Figure 4B).

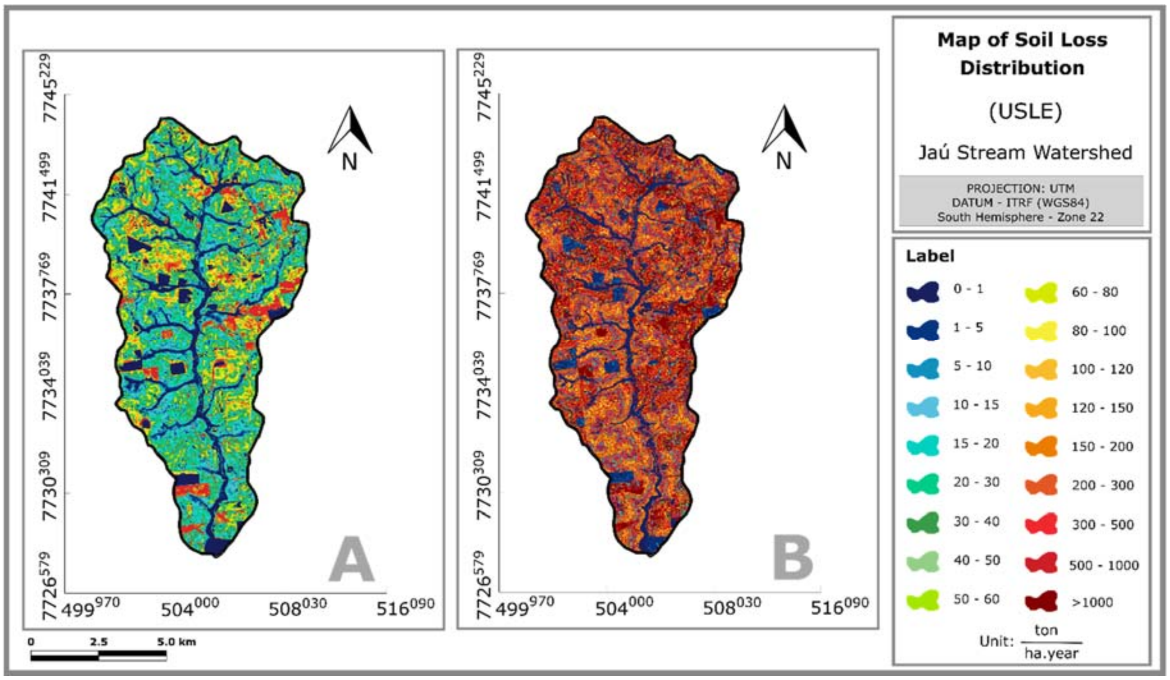

Figure 4. Soil Loss distribution for the Jaú Stream Watershed using the simplified LS factor (Fig. A) and the one obtained through SAGA software (Fig. B).

Table 2 shows the area occupied by each of the eighteen classes of soil loss used to represent the basin, as well as the percentage of area occupied by each of them, with the most significant classes being highlighted in each case.

Furthermore, a comparison was made between the distribution of soil losses obtained from the different combinations of USLE and the location of the sites where erosive processes were found, either by visual identification through satellite images or registered in the Map of Erosive Features. For this purpose, the soil loss classification scale used was suggested by Beskow *et al*. (2009), which divides the soil loss into seven classes, according to Table 3.

Table 4 shows the area and percentage of area occupied by each class of soil loss in this new scale, and the amount and density of erosion processes per class, while Figure 9 displays the spatial distribution of these classes and the erosive processes identified in the study area

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Table 2. Soil Losses in the Jaú Stream Watershed.

	Simplified LS factor		LS factor from SAGA	
Soil Loss	Area (km²)	% Occupied	Area (km²)	% Occupied
0 -1	11.36	13,8%	8.20	10.0%
1 - 5	2.47	3.0%	5.27	6.4%
5 - 10	5.40	6.6%	2.01	2.4%
10 - 15	7.26	8.8%	0.86	1.0%
15 - 20	7.24	8.8%	1.65	2.0%
20 - 30	12.23	14.9%	0.76	0.9%
30 - 40	8.53	10.4%	1.51	1.8%
40 - 50	5.84	7.1%	0.88	1.1%
50 - 60	4.06	4.9%	1.05	1.3%
60 - 80	5.12	6.2%	1.61	2.0%
80 - 100	2.90	3.5%	1.96	2.4%
100 - 120	1.74	2.1%	1.35	1.6%
120 - 150	1.53	1.9%	2.49	3.0%
150 - 200	1.40	1.7%	2.76	3.3%
200 - 300	1.48	1.8%	5.89	7.1%
300 - 500	1.71	2.1%	11.79	14.3%
500 - 1000	1.54	1.9%	17.19	20.9%
> 1000	0.49	0.6%	15.12	18.4%
Total	82.3	100%	8.20	100%

Table 3. Soil Loss classification method suggested in other works.

Classes	Soil Loss ($t.ha^{-1}.year^{-1}$)
Low	0 – 2.5
Low to Moderate	2.5 - 5
Moderate	5 - 10
Moderate to High	10 - 15
High	15 - 25
Very High	25 - 100
Extremely High	> 100

Table 4. Area occupied and amount and density of erosive processes by soil loss class.

Classes	Simplified LS factor				LS factor from SAGA			
	Area (km²)	% Occupied	Erosions	spots/km²	Area (km²)	% Occupied	Erosions	spots/km²
0 – 2.5	12.04	14.6%	5	0.42	11.82	14.3%	6	0.51
2.5 - 5	1.79	2.2%	6	3.36	1.65	2.0%	0	0.00
5 - 10	5.40	6.6%	5	0.93	2.01	2.4%	1	0.50
10 - 15	7.26	8.8%	10	1.38	0.86	1.0%	1	1.16
15 - 25	13.87	16.9%	17	1.23	2.19	2.7%	0	0.00
25 - 100	32.04	38.9%	32	1.00	7.22	8.8%	9	1.25
> 100	9.89	12.0%	14	1.42	56.59	68.7%	72	1.27
Total	82.28	100.0%	89	0.42	82.35	100.0%	89	0.51

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It is observed that for the assessment using the LS Factor obtained from the SAGA software, the absolute majority of the erosive processes identified in the basin is in the areas with the highest soil losses. This fact could indicate the coherence of the method, taking into account the location of the erosive processes, however this extreme loss of soil in most of the basin and the absence of a more distributed soil loss ratio in it raises doubt as to the method's accuracy in representing the real characteristics of the place. On the other hand, the density of erosive processes observed when using the usual LS factor is more evenly distributed.

Despite these analyzes, the erosion density results may not be significant enough for a more in-depth analysis and for conclusions to be drawn from them alone, even because erosions are not punctual as their graphical portrayal. On the contrary, there have been identified several erosive processes that extend over large areas (both laminar and linear processes), so that, in practice, these erosions can extend over areas with different types of soil cover or slope, for example, while its representation suggests only a single class for each parameter.

Therefore, it is understood that the analysis of the location of erosive processes is best accomplished by simple visual analysis, as can be done with Figure 5, where the distribution of erosive processes on the soil loss map is shown using the simplified LS Factor.

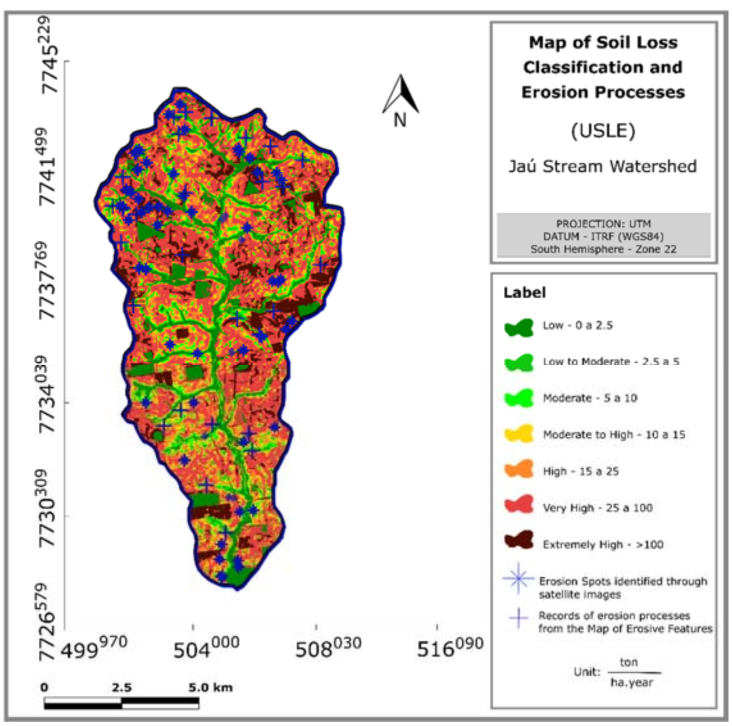

Figure 5. Classified map of soil loss with spatial distribution of the erosive processes identified in the Jaú Stream Watershed using the simplified LS Factor.

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Although it is not possible to verify exactly in which class the spots are located (at least in the scale used) in Figure 5, it is noticed that most regions with the highest concentration of points are also the regions with the highest soil losses in their surroundings. Besides it, the distribution of the area occupied by each class in this situation is increasing in a moderate way, which contributes to the perception that this is the most faithful representation of the study area.

It should be noted that the fidelity of both soil loss and topographic representation is of the most importance for a wide range of studies, as these elements have direct influence in the hydrological behavior of the basin. They influence the volume and speed of runoff, how it is distributed, the infiltration of water, the amount of sediment transported, how the sediment is deposited, among others.

Having a good representation of how the basin behaves in view of the various factors that interfere with it allows for different approaches. The results obtained could lead to following studies as specific as identifying which practices could be implemented in order to reduce the soil loss in specific properties, to broader approaches as how the sediment carried by the runoff of the basin influences in droughts or floods somewhere else.

In addition, Medeiros *et al*. (2016) estimated an average soil loss of 30 $ton.ha^{-1}year^{-1}$ for the entire state of São Paulo. Lino (2010) predicted in his study that 35% of the state was subject to soil loss between 0 and 9 $ton.ha^{-1}year^{-1}$, 50% between 9 and 118 $ton.ha^{-1}year^{-1}$, and 15% above 118 $ton.ha^{-1}year^{-1}$. Meanwhile, Mello *et al*. (2006), in their study of a region with soil characteristics, cover and relief similar to those of the present study, observed a considerable area with soil loss between 20 and 50 $ton.ha^{-1}year^{-1}$. Hence, it can be noted that these values are consistent with the results obtained in the study.

Conclusion

In all the analyzed cases, the land cover and management factor was of great importance for the final result, being also demonstrated the great relevance of the topographic factor. Natural vegetation and exposed soil were considered the land covers with the highest and lowest stability, respectively, in all situations.

As for the differences in the classifications and final maps, it was noted that the map generated by the USLE using the topographic factor called simplified creates the most comprehensive maps with the greatest approximations, with most of the study basin situated in areas with soil losses ranging from 20 to 50 $ton.ha^{-1}year^{-1}$, or high to very high loss, depending on the scale used.

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The map of the Universal Soil Loss Equation produced from the topographic factor obtained in an automated way by the SAGA software was the one that exhibited the most discrepant results, due to local variations and an extreme detailing of this factor for the area, which created soil loss results extremely high for most of the basin, with a predominance of values above 300 ton.ha^{-1}year^{-1}.

It was also verified that the comparison between the soil loss obtained by the different combinations tested and the location of the erosion processes identified in the basin is better accomplished through visual analysis of the maps, and not by the numerical results, due to the nature of the erosive processes.

Finally, it was noticed that the map that seems to better characterize the basin and to be more true to reality is that generated from the USLE using the simplified topographic factor. The predominance of soil loss values ranging between 20 and 50 ton.ha^{-1}year^{-1} is also consistent with the loss of soil estimated by other works in the same context.

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