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USE OF USLE/ GIS TECHNOLOGY FOR IDENTIFYING CRITERIA FOR MONITORING SOIL EROSION LOSSES IN AGRICULTURAL AREAS[1]

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KEYWORDS

soil cover, water erosion, topographic factor, conservation management.

ABSTRACT

The assessment of land use and occupation is essential for predicting soil loss due to water erosion. The objective of this study was to determine criteria for monitoring soil loss in agricultural areas using the Universal Soil Loss Equation (USLE). Soil loss data were intersected with USLE factors and slope using geoprocessing techniques for the Samambaia River watershed, located in Cristalina, Goiás state, Brazil. A slope of 3% to 8% was found in approximately 50% of the study area. However, mean soil losses <10 t ha^{-1} $year^{-1}$ were observed in slopes ≤ 3%, where the mean soil length (L) and slope steepness (S) were ≤2 and 0.2, respectively. The intersection of soil loss data with USLE factors was useful for identifying criteria for monitoring soil loss. The mean topographic factor (LS) in non-irrigated crops, pasture, and silviculture was 0.4 ± 0.4, 0.4 ± 0.7, and 2.2 ± 2.6, respectively. Therefore, LS values adequately indicated the type of land use and occupation considering that only silviculture could maintain soil losses below the tolerable limit of 10 t ha^{-1} $year^{-1}$ for an LS mean of 2.2.

INTRODUCTION

It is common to find cases involving the inadequate use and occupation of land in rural and urban areas. This process can lead to changes in surface runoff, and consequently in the hydrological cycle, and the formation of erosive features, contamination of near-surface and deep groundwater, and the imbalance of the local ecosystem (Nunes & Roig, 2015). For this reason, the analysis of land use and occupation is essential for predicting soil losses due to erosion. This prediction is routinely performed using computational simulation.

Several simulation models, including the Universal Soil Loss Equation/Revised Universal Soil Loss (USLE/RUSLE), Water Erosion Prediction Project (WEPP), European Soil Erosion Model (EUROSEM), and Soil and Water Assessment Tool (SAWT), among others, have been used to estimate soil erosion at the regional level (Prasannakumar et al., 2012). The results of these models have served as the basis for planning land use in watersheds and identifying possible impacts (positive or negative) caused by the extinction of species or changes in soil management due to farming, forestry, and livestock activities (Mello et al., 2016).

The USLE proposed by Wischmeier & Smith (1978) is the foundation for one of the models that are commonly used worldwide, including tropical regions, to estimate water erosion. The model is simple compared to other empirical and physical models and has only six factors: erosivity (R), erodibility (K), slope length (L), slope steepness (S), soil use and management (C), and conservation practices (P). USLE or RUSLE, such as the RUSLE3D model, has been used to develop maps for assessing the risk of soil erosion, particularly in developing countries (Mello et al., 2016). The application of RUSLE in the watershed of the Verde River, south of Minas Gerais, indicated high rates of soil loss in Cambisol regions covered by pastures (Oliveira et al., 2014).

The calculation of the topographic factor (LS) was one of the main limitations to the use of USLE in watersheds. However, new methods were developed for the application of this tool on irregular ridges (Salgado et al., 2012). Research on this topic has addressed the

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automatic calculation of LS in watersheds and the influence of the data scale on the assessment of erosion (Mondal et al., 2016; Oliveira et al., 2013). However, few studies made practical use of the results of the USLE and/or its factors for guiding the conservation management of farming areas.

Miqueloni et al. (2012) conducted a spatial analysis of USLE factors and found that soil loss factors are localized and are affected by K and LS factors in cultivated and forested areas, especially in specific landform reliefs. Therefore, evaluating these factors individually to understand their relationship with soil erosion is essential. The objective of this study was to apply the USLE in agricultural regions to identify criteria for monitoring soil losses due to water erosion.

MATERIAL AND METHODS

The study area is located in the Samambaia River watershed (latitude 15° 58' S and 16° 44' S and longitude 47° 27' O and 47° 39' O) located 40 km from the city of Brasília, Federal District, Brazil, and has a catchment area of approximately 87,500 ha. Its estuary is located on the São Marcos River, on the border with Minas Gerais. Approximately 94% of the watershed area is located in the municipality of Cristalina, Goiás, and only 6% is located in rural areas of the Federal District. The average altitude of the study area is 945 m and the mean steepness is 5% (SIC, 2005).

The climate type of the study area is Aw using Köppen classification, with an annual mean temperature of 23ºC and annual mean rainfall of 1,483 mm (N = 33 years). The rainy season occurs from November to April (according to data from the pluviometric station of Cristalina, located approximately 1 km from the southern border of the study area).

The predominant soil types in the study area are Latosols, Plinthosols, and Cambisols. All soils are dystrophic, with very clayey or clayey gravelly texture, and are located in gently undulating to undulating relief (SIC, 2005). The land use includes agriculture with and without conservation practices. Most of the land in the studied watershed contains annual and perennial crops (irrigated or non-irrigated), with a predominance of soybean crops (*Glycine max* (L.) Merr.), maize (*Zea mays* L.), sweet corn, cotton (*Gossypium hirsutum* L.), and coffee (*Coffea* spp.).

The Universal Soil Loss Equation (USLE) [eq. (1)]* was used as a prediction tool together with geoprocessing techniques to estimate annual soil loss caused by laminar and groove erosions considering factors related to climate, soil, topography, land use and management, and the adoption of supportive conservation practices (Wischmeier & Smith, 1978).

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

where,

A – Soil losses in t ha^{-1} year^{-1}; *Units in the International System

R – Erosivity, MJ mm ha^{-1} h^{-1} year^{-1};

K – Erodibility, t h MJ^{-1} mm^{-1};

L – Slope length, dimensionless;

S – Slope steepness, dimensionless;

C – Soil use and management, dimensionless, and

P – Conservation practices, dimensionless.

R was calculated using the Fournier equation developed by Lombardi Neto & Moldenhauer (1992) and from monthly rainfall data obtained from the National Water Agency (ANA, 2014) using the Hidroweb platform. For this study, data were collected from ten stations located in the Federal District, Cristalina, and surrounding municipalities.

The K values were obtained from the literature for the soil combinations described in the pedological map of the studied area. The mean K (Kμ) was calculated in each soil-mapping unit (Table 1).

TABLE 1. Mean erodibility (Kμ) in soil mapping units from the Samambaia River watershed.

Soil mapping units (Symbols)	Erodibility of the soil combination (th MJ^{-1} mm^{-1})	Mean erodibility (th MJ^{-1} mm^{-1})	Area (ha)	Reference
RYL and DRL[1]	0.020 and 0.014	0.017	33.560	Calixto (2013); Bloise et al. (2001); and Silva (2004)
C and DRL[2]	0.024 and 0.014	0.019	20,030	
FF and C[3]	0.018 and 0.024	0.021	32,111	Calixto (2013)
C e F[4]	0.024 and 0.000*	0.024	1.710	
L and RYL[5]	0.000* and 0.020	0.020	70	
C and RL[6]	0.048 and 0.040	0.044	10	Silva (2004)

[1] Combination of Red-Yellow Latosols (RYL) and Dark Red Latosols (DRL)
[2] Combination of Cambisols (C) and Dark Red Latosols (DRL)
[3] Combination of Petric Plinthosols (FF) and Cambisols (C)
[4] Combination of Cambisols (C) and Plinthosols (F)
[5] Combination of Petroplinthic Latosols (L) and Red-Yellow Latosols (RYL)
[6] Combination of Cambisols (C) and Litholic Neosols (RL). *Not found in the researched literature

For LS calculation, altitude data from the Brazilian geomorphometric database, developed by the National Institute of Space Research (Instituto Nacional de Pesquisas Espaciais–INPE, 2014) using the platform of the Topodata Project, were used for selecting the grid (15S48 and 16S48) compatible with the scale of 1:250,000, with an approximate spatial resolution of 30 m. Slope steepness was extracted from the altimetry data of the Topodata Digital Elevation Model (DEM) and was classified according to Santos et al. (2013).

The topographical factor developed for the watershed was calculated using eqs (2) and (3), proposed by Desmet & Govers (1996) and Nearing (1997), respectively:

$$L_{\mathrm{i,j}} = \frac{\left(\mathrm{A_{i,j}} + \mathrm{D}^2\right)^{m+1} - \left(\mathrm{A_{i,j}}\right)^{m+1}}{\alpha_{\mathrm{i,j}}{}^{m} \times \mathrm{D}^{m+2} \times 22{,}13^{m}} \qquad (2)$$

$$S_{\mathrm{i,j}} = -1{,}5 + \left[\frac{17}{1 + e^{\left(2{,}3 - 6{,}1\,\sin\theta_{i,j}\right)}}\right] \qquad (3)$$

where,

i,j – subscripts representing the coordinates of the grid cell;

$L_{i,j}$ – slope length, dimensionless;

$A_{i,j}$ – contribution area, m^2;

D – DEM grid size, m;

$\alpha_{i,j}$ – flow direction, degrees;

$S_{i,j}$ –slope steepness, dimensionless;

$\theta_{i,j}$ – slope, degrees, and

m – coefficient of adjustment, dimensionless.

These equations were solved automatically using the raster calculator version 10.0 from ArcMap™ for manipulating and generating the above variables.

Imagery acquired from the Terra Imager (OLI) sensor, Landsat 8 satellite, orbit/point (221–71), dated January 5, 2014, available on the World Wide Web, was also used. The land use and occupation map was generated using the per-pixel supervised classification of this software. Soil use and management dimensionless (variable C) from the studies of Stein et al. (1987) and Silva (2004) were used together with the following thematic classes: water bodies (0), riparian vegetation (4 x 10^{-5}), silviculture (1 x 10^{-4}), Cerrado (2.035 x 10^{-2}), pasture lands (0.1), non-irrigated areas (0.18), irrigated areas (0.18), uncovered soil (1.0), mining (1.0), and construction areas (0.1). These thematic classes were identified, mapped, and validated in the study area.

Factor P (conservation practices) was obtained from the studies adapted to Brazil by Bertoni & Lombardi Neto (2012). A field visit to the study area identified the use of conservation practices, including contour planting, with and without agricultural terracing, in most of the farming areas (irrigated and non-irrigated), including sites with uncovered soil, which allowed using a P factor of 0.5 for these classes.

Soil losses (A) were estimated considering only the multiplication of the environmental factors of the USLE (R, K, and LS) to generate the variable designated “natural erosion potential” (N). A and N were classified using interpretation classes, according to Valério Filho (1994) and Carvalho (2008), respectively.

The criteria for monitoring A due to water erosion in the Samambaia watershed were determined using the intersection between the following variables: slope, slope classes, L, S, LS, N, A, and the types of land use and occupation. An average A tolerance of 10 t ha^{-1} $year^{-1}$ was also used as intersection condition, as proposed by Bertoni & Lombardi Neto (2012). For example, areas with an S range of 0 to 3% were selected and intersected with A, and the mean A values in this S range were calculated.

One thousand points were randomly sampled for the statistical analysis of the data. The Kolmogorov-Smirnov normality test at a level of significance of 5% was used to assess data normality. The samples were analyzed using descriptive statistics for measuring central tendency and variability and analyzing the correlation between the USLE factors and the A values generated by the USLE. Student’s t-test ($p = 0.05$) was used to confirm the significance of the obtained correlation coefficients.

The evaluated watershed was divided into three smaller sub-watersheds to facilitate interpretation of the results. This division considered the characteristics of the relief and the watercourses Arrasta-Burro and Ribeirão Moreira tributaries, which are the main tributaries of the Samambaia River. The first division was the Samambaia River sub-watershed with 58,330 ha (67% of the total area), the Ribeirão Moreira sub-watershed with 15,420 ha (17% of the entire area), and the Arrasta-Burro sub-watershed, with 13,748 ha (16% of the total area).

RESULTS AND DISCUSSION

The data did not follow a normal distribution for all analyzed variables (Table 2). For this reason, the correlation coefficient was calculated using the Spearman non-parametric test. Slope length (L), Slope steepness (S), topographic factor (LS), natural erosion potential (N), and soil losses (A) presented a strong positive asymmetry. However, it is of note that erodibility (K), soil use and management (C), and conservation practices (P) values were obtained from the literature and were not calculated in this study. N and A with a non-normal distribution were also found by Miqueloni et al. (2012), mainly because of the variability in relief, erodibility, vegetation cover, and soil management.

TABLE 2. Descriptive statistics and correlation analysis of the variables erosivity (R), erodibility (K), slope length factor (L), slope gradient factor (S), topographic factor (LS), soil use and management (C), crop practices (P), slope angle (D), natural erosion potential (N) and soil losses (A).

Variable	Mean	Median	Standard deviation	CV (%)	AS	K	KS	R_s
^{1}R	7928.94	7901.44	82.55	1.04	1.38	1.75	0.19	0.26*
^{2}K	0.019	0.019	1.83×10^{-3}	9.58	0.16	–1.09	0.24	0.42*
L	2.95	2.16	2.92	98.90	4.58	30.01	0.25	0.86*
S	0.58	0.45	0.51	86.49	3.28	20.59	0.15	0.86*
LS	2.04	1.05	3.02	147.92	3.76	18.54	0.26	–
C	0.27	0.18	0.33	123.18	1.68	1.05	0.44	0.26*
P	0.69	0.5	0.26	37.79	0.11	–1.15	0.37	0.34*
CP	0.15	0.09	0.16	107.56	1.66	1.05	0.45	0.37
D	5.12	4.25	3.91	76.36	1.93	7.10	0.11	0.86*
^{3}N	321.90	161.49	485.78	150.91	3.74	18.10	0.26	0.99*
^{3}A	42.16	14.64	98.88	234.53	8.62	115.65	0.34	0.71*

N = 1000. CV, coefficient of variation (%). AS, asymmetry; K, kurtosis, KS, Kolmogorov-Smirnov (test statistic); R_s, Spearman's correlation coefficient between LS and other variables. ^{1}(MJ mm ha^{-1} h^{-1} years^{-1}); ^{2}(th MJ^{-1} mm^{-1}); ^{3}(t ha^{-1} year^{-1}). *The correlation was significant at a level of significance of 0.01 (two-tailed analysis).

The coefficient of variation was low for R and K using the classification proposed by Warrick & Nielsen (1980), indicating low dispersion and data homogeneity (Table 2). This result may be because of the low spatial variability of the pluviometric and pedological data sampled at the scale of 1:250,000. However, LS, N, and A presented high coefficient of variation, as also reported by Souza et al. (2005). The mean coefficient of variation (CV) for the USLE factors was 61% and was approximately four times higher (235%) for A, indicating a significant propagation of uncertainty in the prediction of USLE, as observed by Chaves (2010). The average CV was increased using LS in detriment to the individual values of L and S.

Calixto (2013) found a lower CV for K compared to the value found by Chaves (2010) (21% and 54%, respectively) for an area located in the same watershed. This result indicates that the database used and changes in data sampling and treatment yielded different results for USLE factors and A for similar conditions in the same study area.

The highest Spearman correlation coefficient was found between LS and N (R_s = 0.99* – significant) (Table 2). This strong correlation may confirm the importance of relief as an important factor in modeling N. Olivetti et al. (2015) demonstrated that the highest LS values were found in areas in which the accumulation of surface runoff was more intense. However, a moderate correlation (R_s = 0.71) was found between LS and A, indicating the influence of relief and other factors such as land use, land management, and conservation practices, which presented a significant correlation (0.61) with LS and A.

Our results indicated that even in areas with high LS, the vegetation cover of the land could attenuate A considerably. This situation was confirmed in the field because the regions with exposed soil presented high erosion rates in contrast to areas covered with eucalyptus (*Eucalyptus* spp.) along the ridge. The spatial distribution of LS and N was similar (Figures 1 and 2 at the scale of 1:40,000).

The occupation of the first three LS classes was similar between the sub-watersheds of the Samambaia River and Arrasta-Burro tributary, and LS was very low (<1) in more than 50% of this area using the classification of Bertoni & Lombardi Neto (2012). In contrast, in the Ribeirão Moreira sub-watershed, 47% and 21% of the total area was assigned to LS classes of 1–5 and > 5, respectively. LS values higher than 5 are considered moderate; however, Oliveira et al. (2014) reported that LS values lower than 10 indicated moderate vulnerability to soil erosion associated with the effect of topography.

The Ribeirão Moreira sub-watershed presented the highest mean LS (3.6), which was almost twice that of the other two sub-watersheds (1.8 and 1.9). Using a geographic information system (GIS) to calculate LS, Weill & Sparovek (2008) observed that in most of the studied area, LS was ≤1.6, which is associated with a slope length and S of approximately 35 m and 10%, respectively.

The highest LS and S values were observed in the middle ridge towards the lower third of the ridge near the tributaries, where there was a convergence of runoff (Capoane, 2013). In this region, approximately 74% of areas with LS values > 5 presented S_{mean} of 13%, i.e., areas with undulating relief. Miqueloni et al. (2012) observed that this LS value was defined by higher S and shorter slope lengths, indicating higher irregularity of the ridges, particularly in the Ribeirão Moreira sub-watershed. These areas are primarily occupied by low- and medium-height native vegetation or pastures, which provide little protection to the soil and increase the risk of erosion.

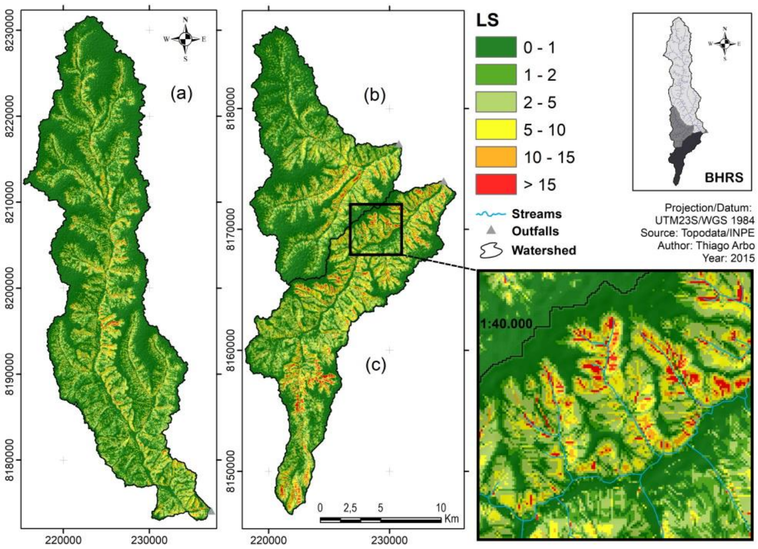

FIGURE 1. Topographic factor (LS) in the sub-basins of Samambaia River (a), Arrasta-Burro Tributary (b) and Moreira Tributary (c). Zoom in on the 1: 40,000 display scale.

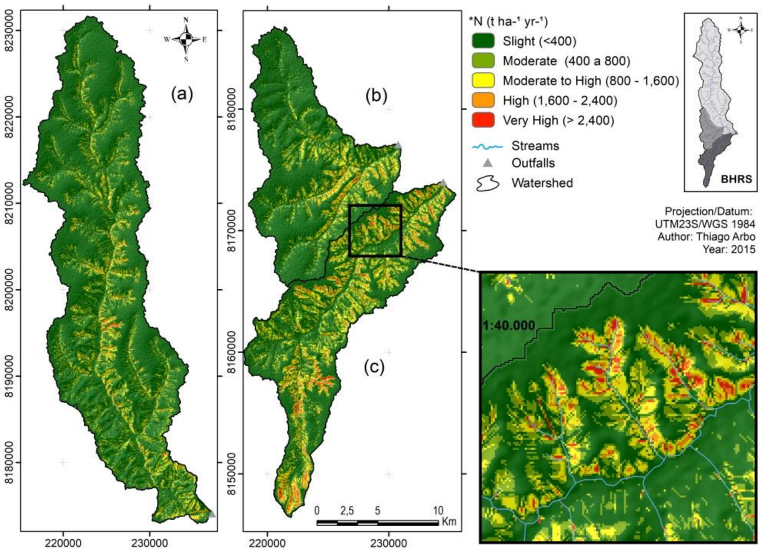

FIGURE 2. Natural erosion potential (N) in the sub-basins of Samambaia River (a), Arrasta-Burro Tributary (b) and Moreira Tributary (c). Zoom in on the 1: 40,000 display scale.

(Source: *Valério Filho, 1994)

A range of S from 3% to 8% was common in the occupied areas, indicating a predominance of smooth undulating relief for the entire Samambaia River watershed (Table 3). The Ribeirão Moreira sub-watershed presented greater amplitude of altimetry data (836 m to 1,248 m), a higher percentage of undulating relief (34.64%) and strong undulating relief (2.19%), and S_{mean} of 11.90% to 23.63%, respectively.

TABLE 3. Area and mean slope, mean (L) and (S) factors, mean (N) and mean (A) per slope range in the sub-basins of Samambaia River, Arrasta-Burro Tributary and Moreira Tributary.

Sub-watershed	Slope (%)*	Area (Km²)	Area	S_{mean}	CV	L	S	N	A
			(%)			(dimensionless)		(t ha^{-1} year^{-1})	
Samambaia River	0–3	217.14	37.23	1.65	50.30	1.86	0.20	90.66	9.83
	3–8	299.05	51.27	5.03	26.24	3.58	0.54	315.00	43.94
	8–20	65.94	11.30	10.72	23.23	4.19	1.25	850.54	103.85
Arrasta-Burro tributary	0–3	51.78	37.66	1.79	42.46	1.93	0.21	61.93	8.77
	3–8	64.11	46.63	4.96	27.62	3.49	0.53	285.29	39.42
	8–20	21.36	15.54	11.04	22.55	4.08	1.30	811.32	96.78
Moreira tributary	0–3	29.64	19.23	1.75	46.86	2.00	0.21	69.84	8.55
	3–8	67.74	43.95	5.35	26.17	3.94	0.58	372.66	48.04
	8–20	53.39	34.64	11.90	24.96	4.39	1.43	992.40	124.62
	20–45	3.38	2.19	23.63	15.79	3.91	3.44	2,089.99	229.28

*According to Santos et al. (2013). S_{mean}, mean slope steepness (%); CV, coefficient of variation (%); L, slope length (dimensionless); S, slope steepness (dimensionless); N, natural erosion potential; A, soil losses.

Soil losses were less than 10 t ha^{-1} year^{-1} for S of $\leq$ 3% (Table 3). The mean L was $\leq$2 and S_{mean} was $\leq$0.21 in all evaluated sub-watersheds, suggesting a specific pattern of soil loss in the Samambaia River watershed, for which the main contributor is topography.

The Ribeirão Moreira sub-watershed presented a mean K of 0.019 th MJ^{-1} mm^{-1} and was classified as intermediate, as suggested by Mannigel et al. (2002). A similar result was observed in the other two sub-watersheds. The highest K (0.044 T h MJ^{-1} mm^{-1}) was observed in the association of Cambisols with Litholic Neosols. This result was similar to that found by Castro et al. (2011). Few studies determined the K values for Plinthosols, particularly in the state of Goiás. Moreover, there is limited regional and updated data and a few pedological maps at larger scales.

The highest N values were observed in the Ribeirão Moreira sub-watershed, ranging from 6 to 130,170 t ha^{-1} year^{-1}, with a mean of 567 ± 300 t ha^{-1} year^{-1}, and this result was similar to that found by Miqueloni et al. (2012). In this respect, Valério Filho (1994) observed that N was low (<400 t ha^{-1} year^{-1}) (Figure 2) in approximately 80% of the area of the sub-watersheds of the Samambaia River and Arrasta-Burro tributary. This result was similar to that found by Oliveira et al. (2015) for the contributory watershed of a small hydroelectric plant in Botucatu, São Paulo state, where the value was <400 t ha^{-1} year^{-1} in approximately 77% of the area. However, there was a 20% reduction in the percentage of low N values in the Ribeirão Moreira sub-watershed compared to the other sub-watersheds, indicating a percentage increase in soils with a higher risk of erosion.

The N values were strongly affected by LS, particularly in the undulating relief, and by K in flat relief or smooth undulating relief. The combination of undulating and strong undulating reliefs in Cambisols and Plinthosols, which covered approximately 75% of the soils of the area, was the primary contributor for obtaining N values >800 t ha^{-1} year^{-1} in the Ribeirão Moreira sub-watershed. In this area, the highest mean N values (780 and 673 t ha^{-1} year^{-1}) were associated with soil mapping units with K of 0.024 and 0.019, respectively. Similarly, the largest mean R-value was found in the association of Cambisols and Plinthosols, with a K of 0.024. However, the two highest LS values (4.4 and 4.0) were observed in soil associations with a K of 0.019 and 0.024, respectively. Despite the small difference between the LS values, N was higher in soil associations in which R and K were increased.

Agricultural areas represented by non-irrigated crops, irrigated crops, pasture, and silviculture, accounted for an average of 70% of the vegetal cover of the soil in the sub-watersheds of the Samambaia River and Arrasta-Burro tributary, where most land uses, including crops and pastures, corresponding to 50% and 20% of the area, respectively, offered limited protection to the soil. The Ribeirão Moreira sub-watershed presented the highest percentage of pastures (approximately 33%).

The highest A values were observed in the Ribeirão Moreira sub-watershed, with a mean of 71 ± 343 t ha^{-1} year^{-1} and median of 20.5 t ha^{-1} year^{-1} (Figure 3). This result was unexpected because the Ribeirão Moreira sub-watershed presented the highest area of Cerrado (20%), riparian vegetation (8%), and silviculture (3%). In addition, this sub-watershed had the lowest percentage of uncovered soil (11%) compared to the other two sub-watersheds. Therefore, the weight of the factors land use, soil management, and conservation practices in these biomes does not seem enough to reduce the natural risk of erosion in this sub-watershed, especially because of the undulating relief in Cambisols (which are considered young and shallow) with native and cultivated pastures, as reported by Oliveira et al. (2014). Furthermore, according to Silva et al. (2014), the estimated risk of water erosion indicated that areas with higher LS and Cambisols should receive more attention.

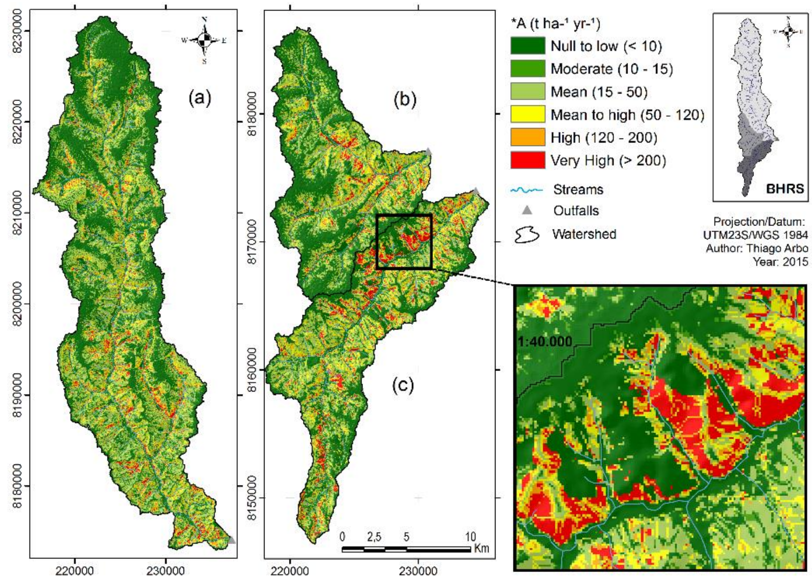

FIGURE 3. Soil losses (A) in the sub-basins of Samambaia River (a), Arrasta-Burro Tributary (b) and Moreira Tributary (c). Zoom in on the 1: 40,000 display scale.

(Source: *Carvalho, 2008)

Although the area of the Samambaia River sub-watershed is four times larger than the Arrasta-Burro tributary sub-watershed, mean A values were similar in these two areas (39 ± 97 t ha^{-1} year^{-1} and 38 ± 87 t ha^{-1} year^{-1}, respectively), indicating that land use and occupation was similar in these sub-watersheds. A. Magalhães et al. (2012) found that A in the Vieira River sub-watershed, in Montes Claros, Minas Gerais state, was 34 t ha^{-1} year^{-1} and S_{mean} was 10%. The results were similar, except for S_{mean} in the evaluated sub-watersheds (5%).

The A values in approximately 35% of the Ribeirão Moreira sub-watershed were lower than 10 t ha^{-1} year^{-1}, which is considered null to small according to Carvalho (2008). This value was common in areas composed of Latosols in flat and smooth undulating reliefs, and S_{mean} was approximately 3%. These soils are usually deep, well drained, and present a higher degree of development and resistance to erosion compared to Cambisols.

The mean A in regions with non-irrigated and irrigated crops was 19 ± 39 t ha^{-1} year^{-1} and 17 ± 28 t ha^{-1} year^{-1}, respectively. However, areas under silviculture and covered by riparian vegetation presented a lower risk of water erosion. The mean A in silviculture regions was only 4.3 t ha^{-1} year^{-1} in the Ribeirão Moreira sub-watershed. However, in uncovered soils, A values reached approximately 285 t ha^{-1} year^{-1}, being characterized as very high, especially in the areas in which forests were cut or silviculture was reduced (Figures 3 and 4; scale of 1:40,000 in the zoom-in area). In this sub-watershed, S_{mean} in silviculture areas was 8%, indicating that this type of land use and occupation occurs when the relief becomes undulating.

Average A values were present in approximately 28% of the studied area (Figure 3). These areas had a predominant of Petric Plinthosols and Cambisols, where mean A values were 43 t ha^{-1} year^{-1} (median of 23 t ha^{-1} year^{-1}) and 71 t ha^{-1} year^{-1} (median of 27 t ha^{-1} year^{-1}), respectively. The soil loss tolerance of common soil types in Brazil is approximately 10 t ha^{-1} year^{-1} (Bertoni & Lombardi Neto, 2012). Similarly, Silva et al. (2009) found that A tolerance values for Cambisols and Latosols in Lavras, Minas Gerais, were 5.6 and 12.7 t ha^{-1} year^{-1}, respectively; thus, the mean A values previously reported for Cambisols and Petric Plinthosols are at least twice the mean tolerance limit for A.

Based on the obtained results, some criteria were established from the intersection between the classes of N, A, LS, and C. For classes with a low N (A < 400 t ha^{-1} year^{-1}), the mean L was 2.06 ± 1.13, and S_{mean} was 0.41 ± 0.26; the mean LS was 0.88 ± 0.67. For soils with null to low A <10 t ha^{-1} year^{-1}), the mean L was 1.95 ± 2.91 and S_{mean} was 0.34 ± 0.31; the mean LS was 0.83 ± 2.22. Therefore, it is possible to consider that LS > 0.8 is a criterion for monitoring risk areas.

The LS values were intersected with the classes with the highest C and A < 10 t ha^{-1} year^{-1} in the study area. Consequently, the mean LS in regions with non-irrigated crops, irrigated crops, and pasture was 0.37 ± 0.36, 0.37 ± 0.20, and 0.43 ± 0.72, respectively. However, for silviculture, the mean LS was 2.23 ± 2.55, which was much higher than the value of 0.8 reported previously. This result demonstrates the importance of silviculture in reducing A to tolerable thresholds, particularly in areas with very irregular relief.

An attempt was made to identify areas (pixels) in the Ribeirão Moreira sub-watershed with the following criteria: a) S > 3%; b) L > 2; c) S > 0.2 d) LS > 0.8. The intersection of these criteria generated a grid that was used to monitor A (Figure 4A). This analysis indicated, A < 10 t ha^{-1} year^{-1} only in areas with riparian vegetation, silviculture, and Cerrado.

After the intersection of these criteria, the mean A in uncovered soils (with an area of 1,458 ha) was 436 ± 1,105 t ha^{-1} year^{-1}. Soil loss may be decreased significantly in areas that use silviculture (with land use, soil management, and conservation practices of 1 x 10^{-4}), with a mean and maximum A of 0.1 ± 0.2 t ha^{-1} year^{-1} and 13 t ha^{-1} year^{-1}, respectively (Figure 4B). Considering our analysis without economic aspects, the use of forestry may be a good option in areas with moderate erosion potential in the Samambaia River watershed in Cristalina, Goiás.

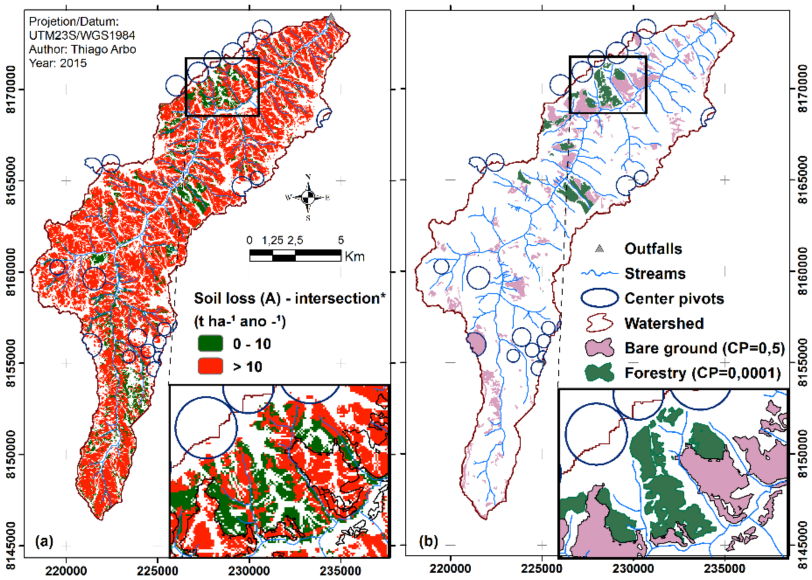

FIGURE 4. Soil losses (A) after the *intersection of the criteria (slope > 3%, factor L > 2, factor S > 0.2 and factor LS > 0.8) for the Moreira Tributary sub-basin (a). Areas occupied by the forestry and bare ground classes (b).

Lastly, we should highlight the occurrence of erosion in areas under silviculture, especially where the soil is exposed and during the rainy season. These results confirm the findings of Silva et al. (2014). Therefore, the planning of forest activities in this watershed should include the implementation of other conservation practices, in addition to those already used, to eliminate exposed areas containing Cambisols, and forestry should be introduced.

CONCLUSIONS

The intersection of A with some USLE factors was useful for identifying criteria for monitoring soil erosion considering that A values lower than 10 t ha^{-1} year^{-1} were found for L and S values of ≤ 2 and 0.2, respectively, and for LS of <0.8.

In the current management conditions of areas cultivated with eucalyptus, LS indicated the type of land use and occupation because only silviculture maintained A values below the tolerable limit of 10 t ha^{-1} year^{-1} for a mean LS of 2.2.

The intersection of the criteria established in this study revealed areas with higher risk of soil erosion within the class of uncovered soils. However, mean soil losses were decreased to values close to zero in regions where silviculture was used. Therefore, these criteria can be used to assist conservation management of forested areas by monitoring soil loss due to water erosion.

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