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FACTORS OF SOIL EROSION IN THE CÓRREGO RICO WATERSHED, SÃO PAULO, BRAZIL

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1 ABSTRACT

This study aimed to estimate soil losses in 1984 and 2011, in Córrego Rico Watershed (CRW) using the Universal Soil Loss Equation (USLE) and propose alternatives that might mitigate the degradation in this area. In erodibility (K) the highest value was in Alfisol Red Yellow and the lowest in Oxisol. For factor S the largest area is in embossed wavy with 33,100.20 ha (57.06%) and slope from 8.1 to 20%. In the factors Vegetation and Soil Management (C) and Conservation Practices (P) it was observed that in these years there were considerable changes such as the reduction of pasture and fruit trees areas and increased areas of cane sugar. A positive balance was increased vegetation cover of 1,993.95 ha in 1984 to 4,895.25 ha in 2011. The highest soil loss in the class occurred in an area of 26.44% in 1984 and 2011 in an area of 30.22%. The integrated use of USLE and GIS proved to be an effective technique in the spatial representation of soil loss in Córrego Rico watershed to identify areas most vulnerable to erosion process and in spatial-temporal variability.

Keywords: USLE, land use, map algebra

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2 RESUMO

Este trabalho teve por objetivo estimar as perdas de solo nos anos de 1984 e 2011, na bacia hidrográfica do Córrego Rico (BHCR), utilizando a Equação Universal de Perda de Solo (EUPS) e propor alternativas que possam mitigar a degradação nesta área. Na erodibilidade (K) o valor mais elevado foi no Argilossolo Vermelho-Amarelo e o menor no Latossolo Vermelho. Para o fator S a maior área está em relevo ondulado com 33.100,20 ha (57,06 %) e

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Declividade entre 8,1 a 20 %. Nos fatores Cobertura Vegetal e Manejo do Solo (C) e Práticas Conservacionistas (P) nota-se que nestes anos houve grandes mudanças tais como a diminuição das áreas de pastagem e frutíferas e o aumento das áreas de cana-de-açúcar. Um saldo positivo foi o aumento da cobertura vegetal de 1.993,95 ha em 1984 para 4.895,25 ha em 2011. A maior perda de solo na classe, ocorreu numa área de 26,44 % em 1984 e 2011 em uma área de 30,22 %. O uso integrado de EUPS e SIG mostrou ser uma técnica eficaz na representação espacial das perdas de solo na bacia hidrográfica do Córrego Rico para identificação das áreas mais vulneráveis ao processo erosivo e na variabilidade espaço-temporal.

Palavras–chave: EUPS, uso do solo, álgebra de mapas

3 INTRODUCTION

Erosion is one of the most significant forms of watershed degradation, greatly influenced by improper soil use and management, causing the removal of the fertile topsoil. Watersheds are increasingly important as a unit of natural resources to soil use, planning, conservation and management of urban and rural systems (JIANG et al., 2012; SALGADO, 2011; PISSARRA et al., 2010).

The estimated of erosion by USLE (Universal Soil Loss Equation) is greatly simplified and reduced to five main factors. Its chief advantage lies in its simplicity, ease of application and the small number of input data required (WAGENER, et al, 2013). The USLE model consists of independent factors that assess the erosive potential natural features of the physical environment and human intervention (human action) related in a given area (SALGADO, 2011) and uses by this equation: A = R K LS C P (WISHMEIR; SMITH, 1978).

The ground cover provided by crop residue has effective action in reducing water erosion, due to the dissipation of the kinetic energy of rain drops, decreasing the breakdown of soil particles. For the determination of these factors is necessary the existence of good historical series of rainfall data (SILVA, MARTINS, GUERRA, 2013; CARVALHO, 2013; MARQUES, 2013; RIBEIRO, 2012). Murphy et al. (2013) quantified the annual erosivity, adding EI_{30} values (index of erosivity) of all individual storm events exceeding 12.7 mm. Erodibility (K) shows variations depending on the characteristics of the material constituting the soil type. This difference is due to soil properties which provides a greater or lesser erosion area. These properties are related to infiltration rate, permeability, storage capacity, resistance to dispersion forces, splashing water, abrasion and transport by rainfall and runoff (CEMIN et al., 2013; WANG et al, 2013).

The L and S factors, respectively Length of Ramp Slope and Slope, reflect the effects of topography on soil losses caused by water erosion. More specifically, L is defined as the distance from the origin point to outflow point by decreasing the slope, occurs deposition or outflow in well-defined channels, while S is the influence of slope gradient on soil losses (FERNANDES et al., 2014). Steeper slopes produce flow rates higher on the soil. Long slopes accumulate larger flow areas and also results in higher flow velocities. Thus, both result in increased erosion potential, but in a nonlinear fashion. Different studies have associated the exponent for the soil loss variation with percentage of the Slope (AHMAD; VERMA, 2013).

Between the factors of USLE, LS is considered a major contributor to the loss of soil, which represents a combined effect of the length and the degree of slope (VALLADARES et al., 2012). The factors Vegetation and Soil Management (C) is used separately from factor

Conservation Practices (P) when the aim is to define more appropriate forms to minimize the impact caused by agriculture (GURGEL et al., 2011). Costa et al. (2013a, 2013b) studied the processes of transformations of use and land cover and its main determinants, demonstrating the intensity and location of these, calling attention to the analysis of the impacts such changes as the importance of management along with rural activity for the region and sustainability in the context of watersheds (XAVIER, SILVA, SILVA, 2013).

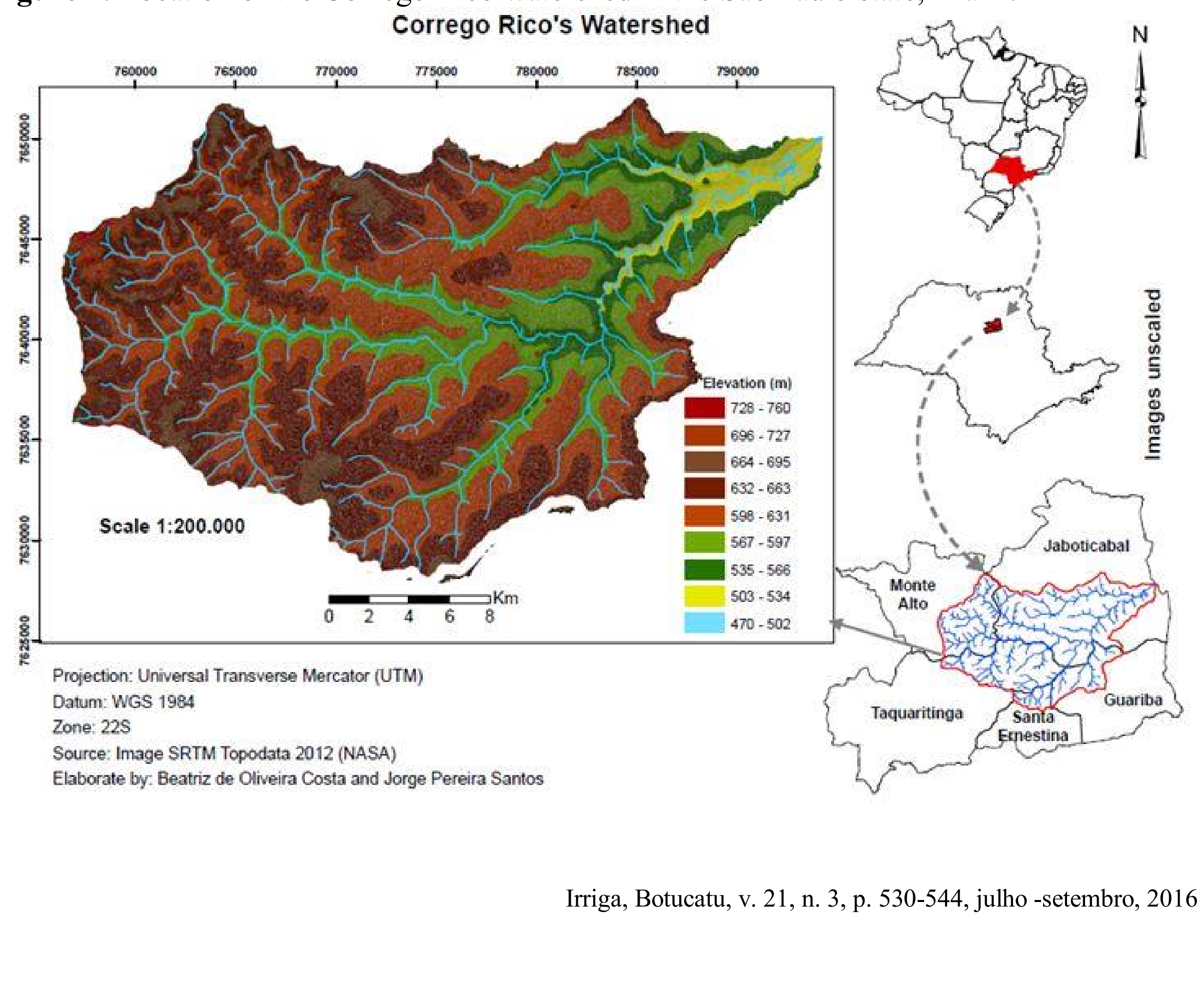
The factor P associates the tax of erosion expected, originating from the use of Conservationist Practices such as outline planting, alternate cultivation and retention strip, with inadequate practices, as culture implanted in the same slope direction (hill below), without the use of the outline cultivation and mechanical barriers. This factor, together with the factor C represents practices destined to reduce the erosion, with the appropriate soil management (DIDONÉ, 2013). Corbeels et al. (2014) accomplished a case study in the lake Alaotra in Madagascar, exploring the practice impact of CA (conservation agriculture) on the total net profit attaché's family, in a medium term (10 years). The factors R, K and LS depend on the natural climate conditions, soil and topography, while the factors C and P relate to human actions, by way of soil use, occupation and management (MIQUELONI, BUENO, FERRAUDO, 2012).

The main objective of this study was to estimate soil losses in 1984 and 2011, in the Córrego Rico watershed (CRW) using the Universal Soil Loss Equation (USLE) and propose alternatives that might mitigate the degradation in this area.

4 MATERIAL AND METHODS

4.1 Study Area

Figure 1. Location of the Córrego Rico watershed in the São Paulo state, Brazil.



The study was conducted in the Córrego Rico watershed (CRW) located in the northeast of São Paulo' state (Figure 1), in the Municipality of Ribeirão Preto.

The watershed is bound to River Mogi-Guaçú Watershed Committee, according to the Hydrographic Division of the São Paulo state (SÃO PAULO, 1994), South American Geodetic System 1969 (SAD 69) with extension of approximately 579.00 km^2, altitudes between 497-754 m (TOPODATA, 2012).

The area includes the following municipalities: Jaboticabal (37.79%), Monte Alto (30.49%), Taquaritinga (21.08%), Santa Ernestina (17.17%) and Guariba (21.56%).

4.2 Cartographic Base and programs used

The TOPODATA (Geomorphometric Database Brazil), created in 2012, was used to obtain the DEM (Digital Elevation Model) and the Google Earth has helped as landscape simulator. The vectors created in these areas were compared with the results of ArcGIS. The Earth Point was used to calculate the area of polygons vectorized in Google Earth program. Most of the work was developed in ArcGIS as the extraction of watershed delineation, establishment and calculation of USLE factors.

4.3 Universal Soil Loss Equation (USLE)

The USLE was applied in CRW to verify soil loss according to the work developed by Wischmeier and Smith (1978) with Equation: A = R K LS C P. For maps preparation of each factor of equation was used GIS techniques like ArcGIS, TOPODATA, INPE (2010), EMBRAPA, Google Earth and Earth Point.

The erosive potential map (R) was developed from data Erosivity of work by Santa'Anna (1995) and Arraes (2009). The map factor Erodibility (K) was prepared from the data of the main soils of the region. To find the values of erodibility of each soil an average was performed with the data obtained from studies developed by by Mannigel, Carvalho and Moreti (2002), Helm (2008) and Demarchi (2012). To elaborate the Ramp Length map (L) was necessary to import the digital elevation model and determine the lowest and highest areas, forming the main drainage network with the direction runoff, rainwater that is, the flatter areas drainage network (flow accumulation). The Slope map (S) was prepared from the digital elevation model, TOPODATA (2012).

The classification followed criteria presented by Embrapa (1999). The factors Vegetation and Soil Management (C) and Conservation Practices (P) maps, were obtained through satellite images from Landsat 5TM, for the years 1984 and 2011, in TIFF format, the image catalog of the National Institute for Space Research (INPE, 2010). The classes established for use and occupation were: 1) Fruit; 2) Forest; 3) Water; 4) Bare Soil; 5) Cities / Buildings; 6) Grassland; 7) Pinus / Eucalyptus; 8) Other Uses and 9) Sugarcane. These classes were established according to the soil use predominant in the area with the aid of Google Earth and vectorization. The factor P map was prepared from the data of work developed by Demarchi (2012), Tomaz (2010) and Domingos (2006). For the maps algebra of USLE was adopted for each factor of equation a score, depending on the degree of importance of each factor to area of the Córrego Rico watershed, according to the method of Analytical Hierarchy. The Analytic Hierarchy Process (AHP) is a semi-quantitative method, that consists of following five steps: (a) break a problem into components of decision factors; (b) arrangement of these factors in a hierarchical order; (c) assigning numerical values to determine the relative importance of each factor according to its subjective importance; (d) creation of a comparison matrix; and (e) the principle of own standard calculation, which gives weight to each factor (KAYASTHA, DHITAL, SMEDT, 2013).

5 RESULTS AND DISCUSSION

The area in hectare (ha) and percentage (%) are shown in Tables 1 and 2.

Table 1. Factors Vegetation and Soil Management (C), Conservation Practices (P), area in ha and %.

Classes	Factors				1984 – Area		2011 – Area		Change
	C	Note	P	Note	(ha)	(%)	(ha)	(%)	(%)
Water	0.00000	1	1.00000	8	84.96	0.15	93.42	0.16	0.01
Forest	0.00378	2	0.90000	7	1,993.95	3.43	4,895.28	8.44	5.01
Cities/Buildings	0.01033	3	0.70000	6	2,476.71	4.27	4,217.76	7.27	3.00
Pasture	0.01992	4	0.30000	5	14,999.85	25.83	2,557.89	4.41	-21.42
Pinus/Eucalyptus	0.02387	5	0.60000	4	554.76	0.96	258.21	0.45	-0.51
Fruit	0.08000	6	0.50000	3	3,217.41	5.54	162.63	0.28	-5.26
Cane/Other Uses	0.18450	7	0.40000	2	32,418.81	55.83	43,126.83	74.35	18.52
Bare Soil	1.00000	8	0.08000	1	2,316.78	3.99	2,689.56	4.64	0.65

C – Vegetation and Soil Management; P – Conservation Practices

Table 2. Factors erosivity (R), erodibility (K), topography (LS), area in ha and %.

Factor		Variables			Area		Note
					(ha)	(%)	
R	(MJ mm h-^{1} ha-^{1} yr-^{1})	Cities	Jaboticabal	7,789	26,868.51	46.33	1
			Guariba	7,831	5,722.20	9.87	2
			Taquaritinga	7,936	12,570.03	21.67	3
			Santa Ernestina	7,952	2,236.68	3.86	4
			Monte Alto	7,984	10,598.49	18.27	5
K	(t h MJ^{-1} mm^{-1})	Soils	LV18	0.00608	22,162.68	38,21	2
			LV1	0.00968	13,712.58	23,64	4
			PVA77	0.02038	9,119.25	15,72	6
			PVA80	0.02838	13,001.40	22,42	8
LS	(dimensionless)	Topography	Very low	0.5 - 1	35,389.62	61.02	1
			Low	1.1 - 1.3	8,674.47	14.96	2
				1.4 - 1.7	11,714.67	20.20	3
				1.8 - 3.3	1,231.02	2.12	4
				3.4 - 5.5	726.3	1.25	5
			Moderate	5.6 - 7.5	183.96	0.32	6
			High	7.6 - 15	76.05	0.13	7

LV – Oxisol; PVA – Alfisol Red-Yellow

And the average annual soil loss of the years 1984 and 2011 as shown in Table 3.

Table 3. Average Annual of Soil Loss for the years 1984 and 2011.

Classification (SILVA, MARTINS, GUERRA, 2013)	Soil Loss ($t\ ha^{-1}\ yr^{-1}$)	1984 – Area (ha)	(%)	2011 – Area (ha)	(%)
	0 – 2	387.00	0.67	410.04	0.72
Null	2.1 – 5	2,485.00	4.30	2,520.00	4.40
	5.1 – 10	6,731.00	11.66	4,989.06	8.72
Middle	11 – 15	13,994.00	24.24	17,297.91	30.22
Average	16 – 20	7,987.00	13.83	16,443.99	28.73
	21 – 50	15,266.00	26.44	11,348.01	19.82
Strong middle	51 – 75	8,420.00	14.58	3,244.77	5.67
	> 75	2,464.00	4.27	991.26	1.73
	Total	57,734.00	100.00	57,245.04	100.00

The maps for factors EUPS are in accordance with Figures 2, 3, 4 and 5.

Figure 2. Topographical map.

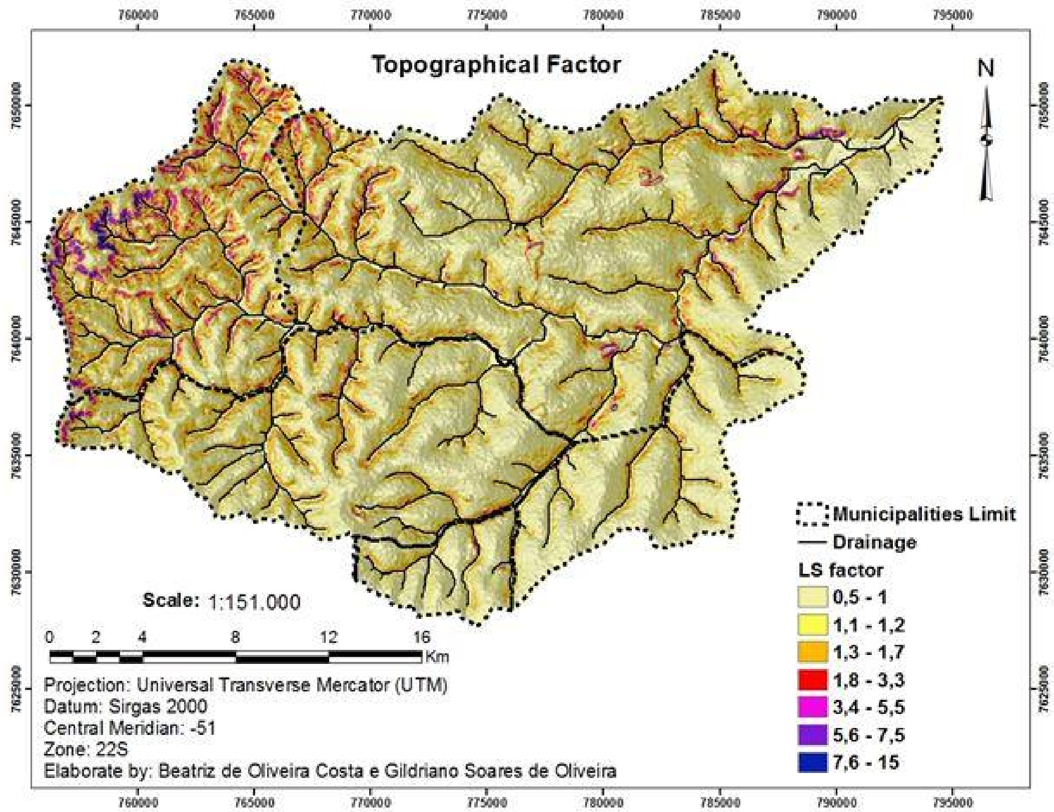


Figure 3. Erosivity and Erodibility maps.

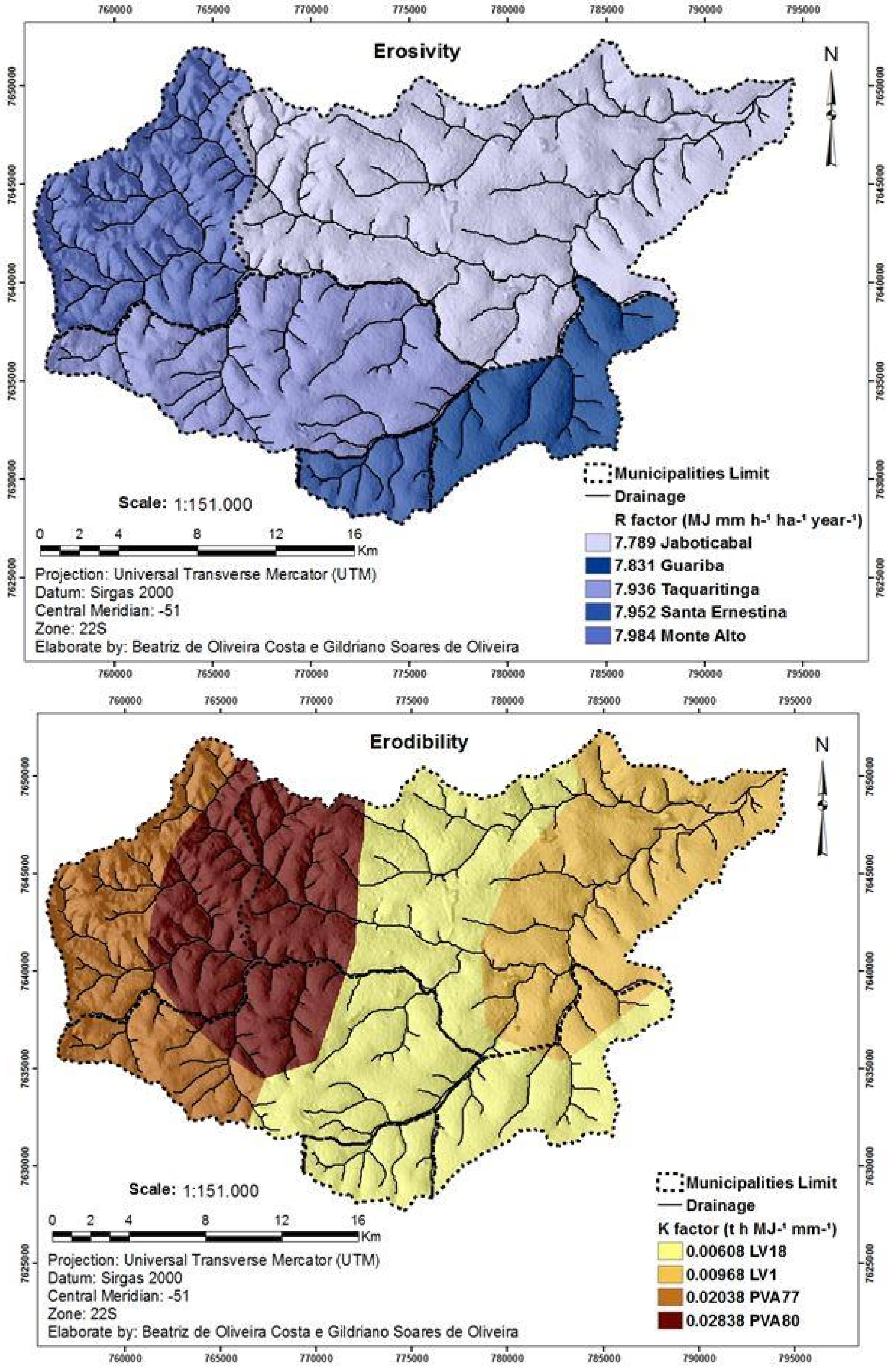
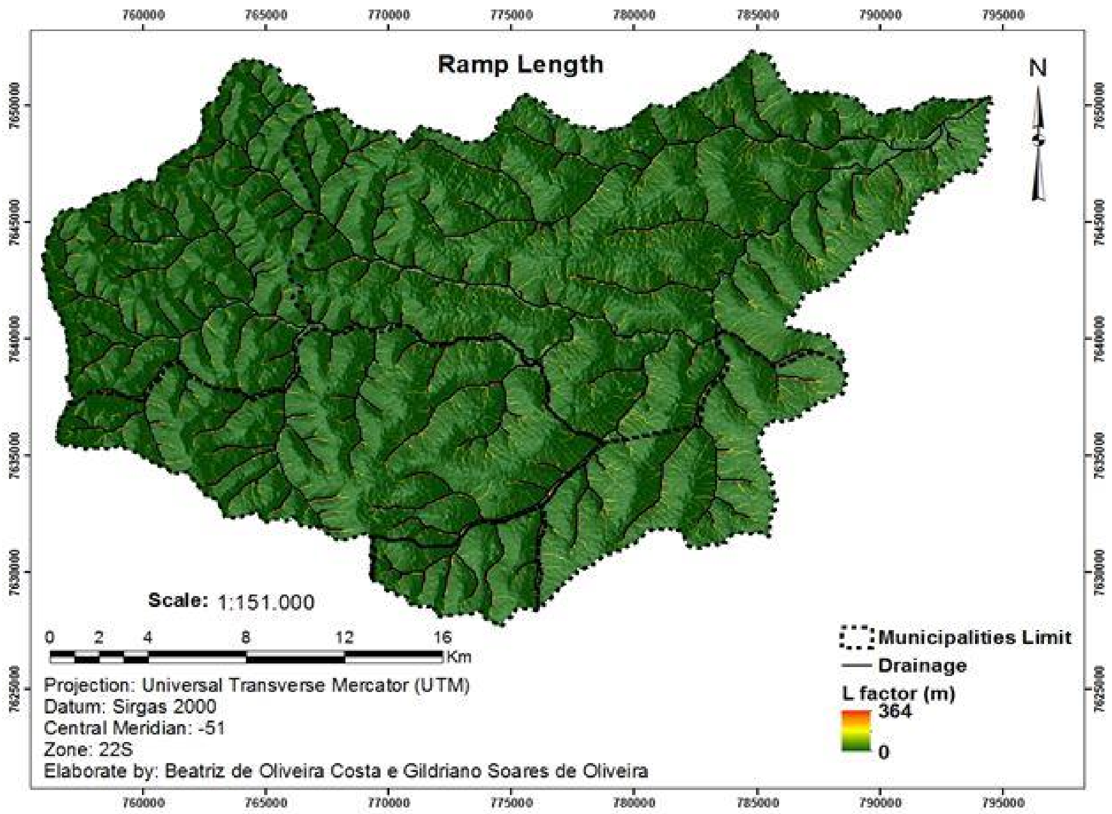


Figure 4. Ramp Length and Slope maps.



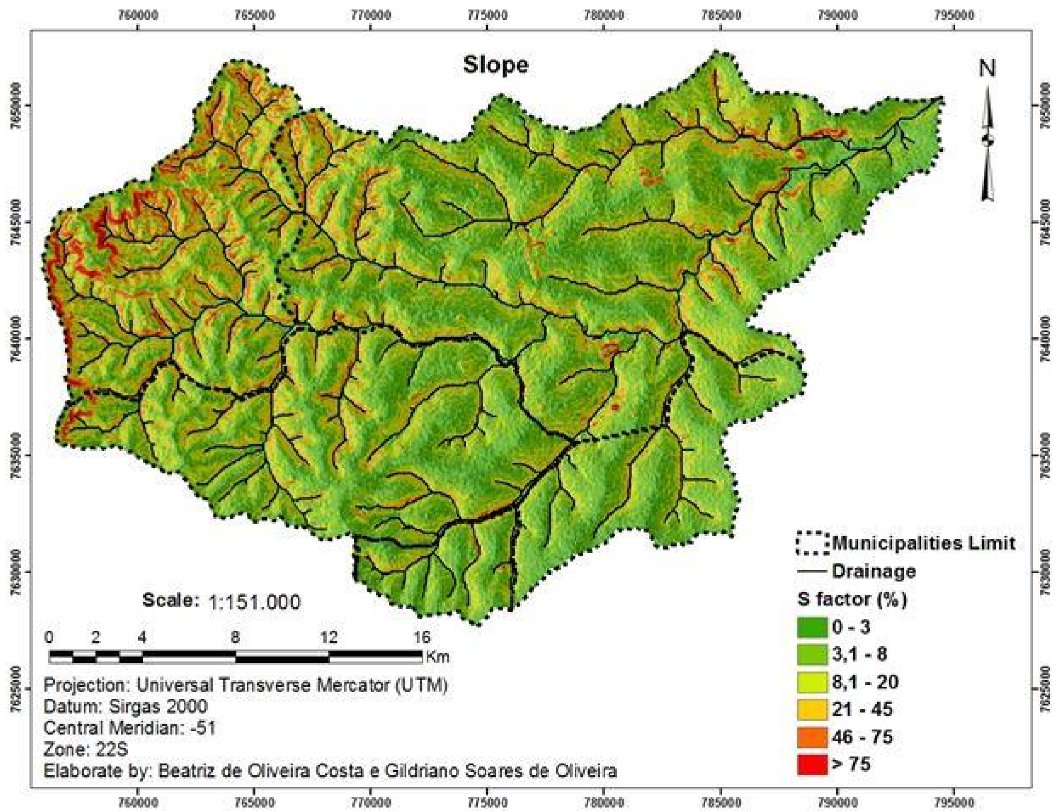
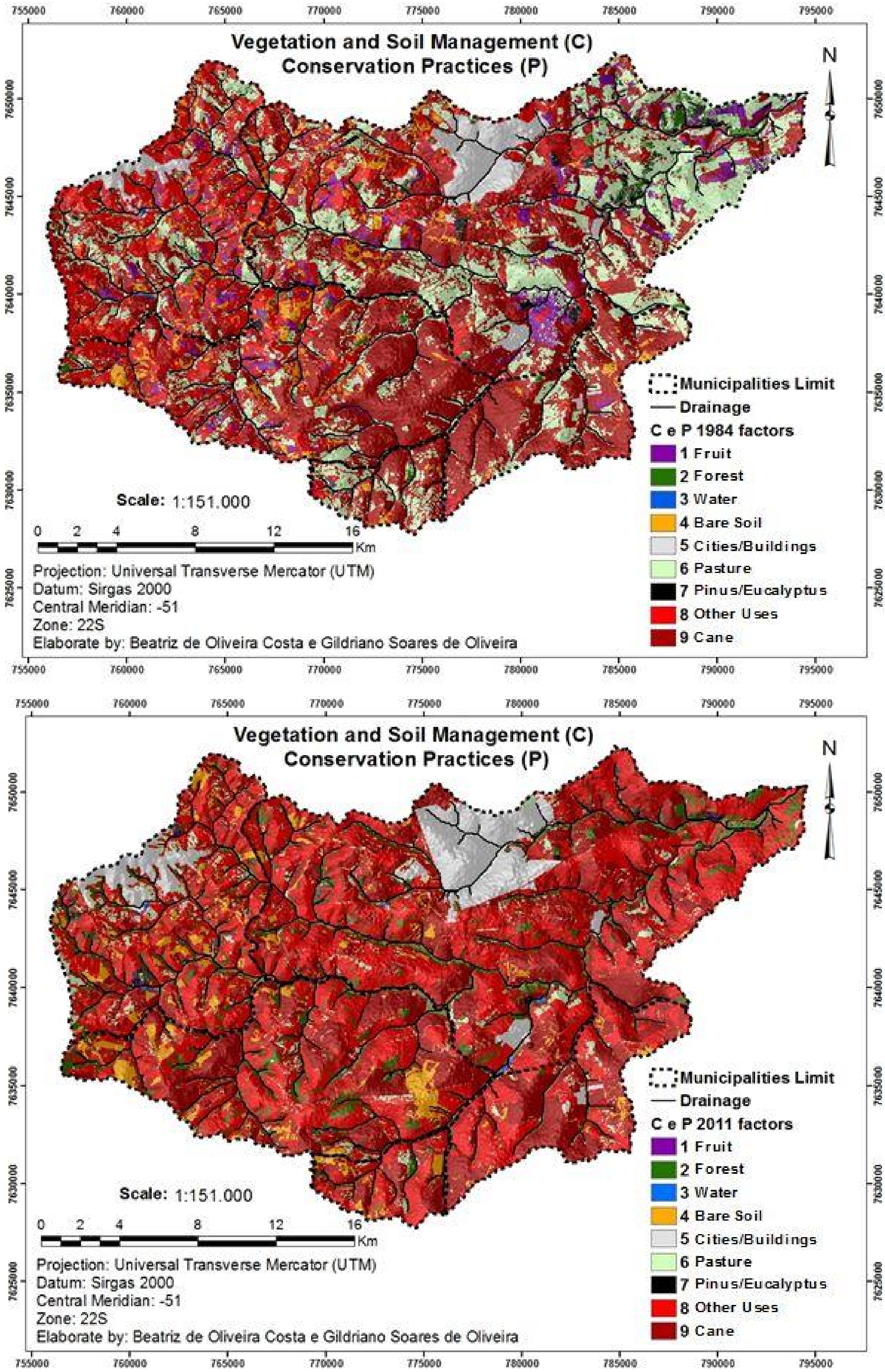
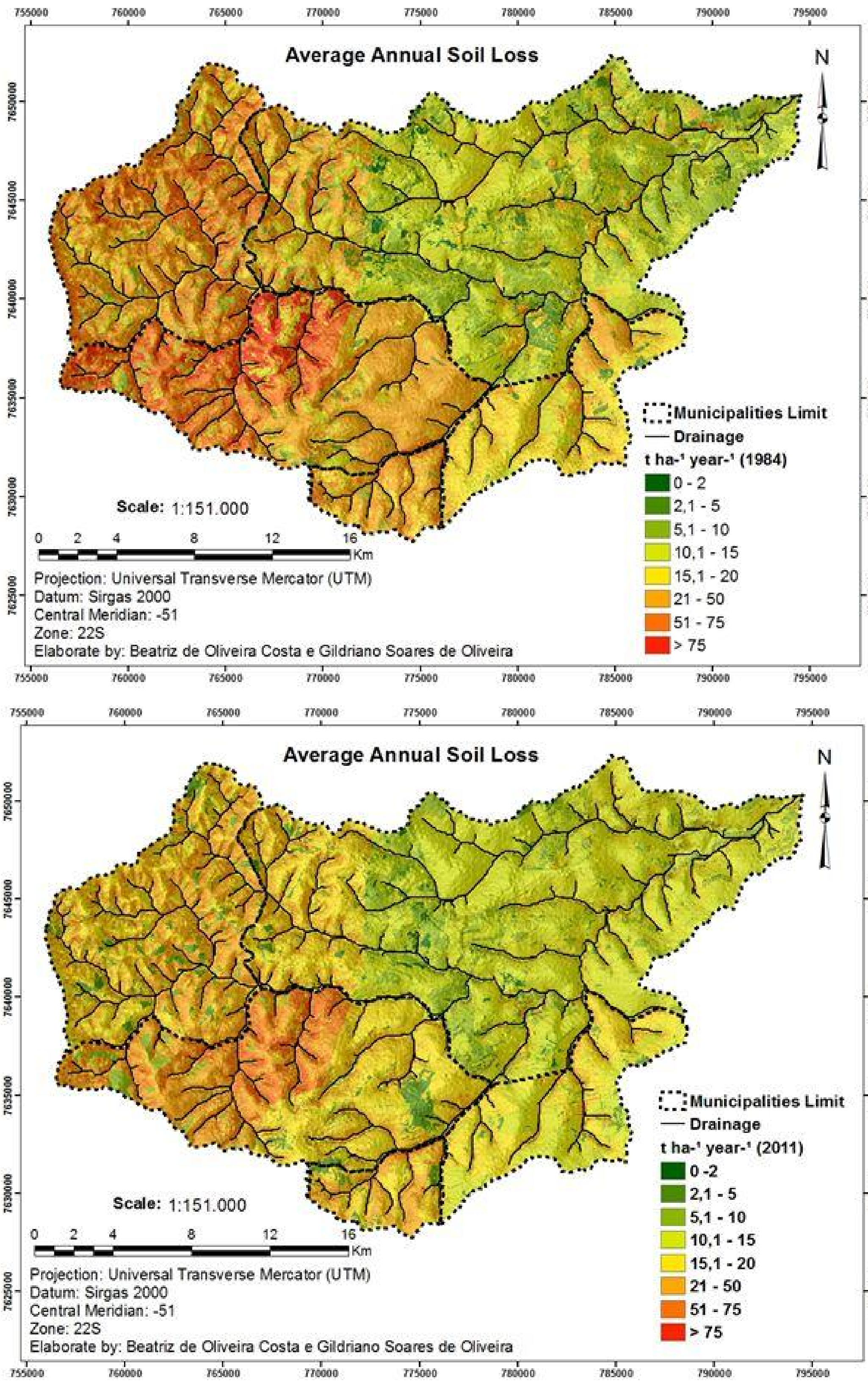


Figure 5. Factors C and P maps of the years 1984 and 2011.



Results after the map algebra as Figure 6.

Figure 6. Soil loss maps of the years 1984 and 2011.



The factor erosivity (R) was higher in the region of Monte Alto where Alfisol l occurs, with 7,984 MJ mm ha^{-1} h^{-1} yr^{-1} (18.27% of CRW) and lowest in Jaboticabal where Oxisol occurs with 7,789 MJ mm h^{-1} ha^{-1} yr^{-1} (46.33% of CRW).

The values found in the CRW can be considered among medium-low erosivity, agreeing with Santa'Anna Neto (1995), results showed values among 5,580 MJ mm ha^{-1} h^{-1} yr^{-1} and 12,680 MJ mm ha^{-1} h^{-1} yr^{-1} with an average of 9,130 MJ mm ha^{-1} h^{-1} yr^{-1} in the state of São Paulo.

In factor Erodibility (K) the highest value was 0.02838 t h MJ^{-1} mm^{-1} with an area of 13,001.40 ha in Alfisol Red Yellow and lower value of 0.00608 t h MJ^{-1} mm^{-1} in Oxisol red with an area of 22,162.68 ha, corroborating the work of Ferraz et al. (2013), with respect to soil types of the watershed, note that those with predominantly Ultisols, have higher values of erodibility, due to texture extremely sandy of the surface layer and the higher concentration of clay in the subsurface horizon, coupled with low levels of organic matter and the high percentage of clay dispersible in water.

The factor LS for the largest area is on a steep slope with 35,389.62 ha (61.02% of CRW) according to the classification of Embrapa (1999), particularly in headwater areas, defined by higher slopes and lower lengths ramp, which indicated greater movement of relief.

In factors Vegetation and Soil Management (C) and Conservation Practices (P) the classes identified were driven primarily by production systems in the region. The forest area has grown over the analysis period, from 3.43% to 8.44% of the area. This increase was due to reforestation processes that were deployed in the region, according to the Brazilian Environmental Legislation calling for reforestation in areas of permanent preservation.

The class cities / buildings also showed an increase, in view of the process of urbanization of major cities, Monte Alto, Jaboticabal and Córrego Rico district. The class of pasture was a drastic reduction in area (-21.42%). This occurred due to implementation of the production system of sugarcane in these areas.

The landuse for planting sugarcane is intense, due to the number of sugarcane companies near the study area and for having the best economic value at the expense of other productive systems mills.

In 1984, the highest soil loss was between 20.1 and 50 t ha^{-1} yr^{-1} in an area of 15,222.33 ha (26.57%) and in 2011 between 10.1 and 15 t ha^{-1} yr^{-1}, area of 15,846.57 ha (27.65%).

Nery and Lima (2013) in the determination of soil loss by superficial erosion in a watershed in Minas Gerais State, observed that the heaviest losses occurred by the association of lack of ground cover and steep slopes, in agreement with this work.

Oliveira and Vanzela (2010) determined the water balance with use of GIS in the Fernandopolis city, SP, at sugarcane culture, tool extremely important for the environmental hydro.

6 CONCLUSIONS

The use of USLE associated with geoprocessing techniques, proved to be a good quality and applicability tool for simulation and mapping of erosion in watershed scale, is promising for studies related to the conservation of water and soil, identifying sectors with the greatest potential erosive and consequently, the most appropriate conservation techniques.

Soil loss in CRW was from zero to 75 t ha^{-1} yr^{-1} with the largest area ranging from 10 to 15 t ha^{-1} yr^{-1}.

From these data is needed establish new studies on cultural practices and soil management, a technology that allows the future management actions in the agricultural production system that conserves soil in continuous dynamic process.

The use of GIS ArcGIS was effective in data processing, map algebra and in the preparation of thematic maps.

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