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ESTIMATES OF SOIL LOSSES IN WATERSHED UNDER TROPICAL OF ALTITUDE CLIMATE IN BRAZIL

SUMMARY

Water erosion is one of the main degradation processes of tropical soils. In steepest areas with coffee cultivation, the erosion rates are intensified and could reach levels above the Soil Loss Tolerance Limits (T). Thus, the objective of this work was to evaluate the susceptibility to water erosion in steepest areas under predominant coffee cultivation using the Revised Universal Soil Loss Equation (RUSLE) and compare the results to T limit. The research was carried out at the Ribeirão José Lúcio subbasin located in Conceição do Rio Verde Municipality and the Ribeirão São Bento subbasin located in Cambuquira Municipality, both in South of Minas Gerais State, Brazil. The parameters involved in the RUSLE and T calculations were determined from the physical and edaphoclimatic characteristics of the subbasins. The total soil loss of the Ribeirão São Bento subbasin was 1,032 Mg year^{-1}, while the Ribeirão José Lúcio subbasin present an erosion rate of 5,014 Mg year^{-1} with 13.16% and 7.90% of the areas above the T limits, respectively.

We found the highest losses in steepest and exposed soil areas, which should be prioritized in the adoption of conservation management practices, seeking to minimize water erosion, and ensuring the long-term sustainability of agricultural production. The RUSLE model is a fast, simple, and inexpensive tool that contributes to the assessment of soil conservation in hydrographic subbasins.

Keywords: Erosion Modeling, Soil Conservation, Water Erosion, Revised Universal Soil Loss Equation, RUSLE.

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INTRODUCTION

Soil is one of the most important and most complex natural resources, but current developments (climate change, soil erosion, and urbanization) increasingly threaten this valuable resource (Ayer *et al.*, 2020; Spalevic *et al.*, 2020; Chalise *et al.*, 2019; Parsipour *et al.*, 2019; Curovic *et al.*, 2019.). Soils are essential for food production and various other ecosystem goods and services, including climate regulation and nutrient cycling (Greiner et al., 2017).

Soil degradation caused by erosion and rapid population increase is ranked among the most important environmental problems in the world (Khaledi Darvishan *et al*., 2019; Dimotta *et al*., 2017; Spalevic et al., 2016; Dimotta *et al*., 2016). Erosion is a key driver of land degradation, heavily affecting sustainable land management in various environments worldwide (Ouallali *et al*., 2019; Tavares *et al.*, 2019; El Mouatassime *et al.*, 2019; Nikolic *et al.*, 2018; Spalevic, 2011). Water erosion is one of the main processes of tropical soil degradation and causes organic matter and nutrients losses, compromising the provision of soil ecosystem services (Olivetti *et al.*, 2015; Bertol *et al.*, 2007). According to Lal (2014), 1 billion hectares worldwide have already been affected by the erosion process, of which 70% are seriously committed to agricultural production. The worldwide annual rate of soil erosion from agricultural land ranges from 22 to 100 t ha^{-1}; declines in productivity as much as 15–30% annually (Morgan, 2005).

Estimating soil loss and identifying hotspot areas support combating soil degradation (Girmay *et al.*, 2020). Direct field measurements of soil erosion at permanent research or experimental stations using runoff plots with the known area, slope gradient slope length, and soil type could give reliable runoff and soil loss (Hurni *et al.*, 2010) for experimental purposes, however, it is costly, labor-intensive, and time-consuming (Alemayehu & Alamirew, 2012). Empirical-statistical models were developed and improved to evaluate and quantify water erosion (Hazbavi *et al.*, 2020; Amorim *et al.*, 2010; Spalevic, 1999). These models include the Universal Soil Loss Equation - USLE (Wischmeier and Smith, 1978) and the Revised Universal Soil Loss Equation - RUSLE (Renard *et al.*, 1997). RUSLE has a simple application and can be adapted to new geographical and edafoclimatic conditions. Moreover, combined this model with geographic information systems (GIS), it is possible to assess the spatial distribution of soil losses and identify areas most susceptible to erosion (Avanzi *et al.*, 2013). Furthermore, soil losses can be compared with the soil loss tolerance (T) limits, which represent the maximum erosion rate that allows sustainable agricultural production (Wischmeier and Smith, 1978).

Coffee is the main agricultural crop in southern Minas Gerais, with economic and social prominence. Coffee plantations are concentrated in steepest areas, which are more vulnerable to water erosion. However, few studies evaluate the dynamics of the erosive process in these areas. Thus, the objective of this work was to evaluate the susceptibility to water erosion in steepest areas under predominant coffee cultivation using the RUSLE and compare the results to the T limit.

MATERIAL AND METHODS

Study area

The research was carried out at the Ribeirão José Lúcio subbasin located in Conceição do Rio Verde Municipality, coordinated 473000 at 477000 m W and 7581000 at 7584000 m S, and the Ribeirão São Bento subbasin located in Cambuquira Municipality, coordinates 479000 to 484000 m W and 7570000 to 7575000 m S, Datum SIRGAS 2000, zone 23K UTM, both in southern Minas Gerais, at high altitudes (> 1000 m) in Serra da Mantiqueira, Brazil (Figure 1).

According to the Köppen system, the climate is classified as humid mesothermal, tropical of altitude subtype (Cwb), with an average temperature of 20° C and precipitation between 1,480 to 1,700 mm (Sparovek *et al.*, 2007). In both municipalities, coffee production is the main economic activity (Figure 1).

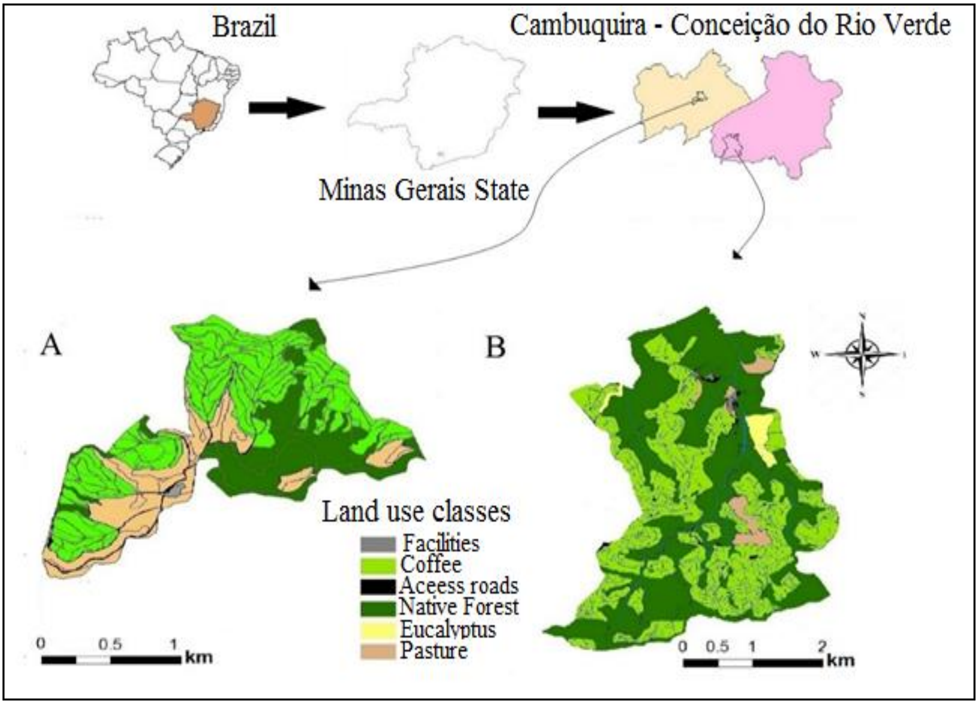

Figure 1: Location and land use and occupation maps in the Ribeirão São Bento (A) and Ribeirão José Lucio (B) sub-basins respectively in the municipalities of Cambuquira and Conceição do Rio Verde, southern of Minas Gerais, Brazil.

The elaboration of the land use map was made from the cartographic base and the crops mapped by Ipanema Agricola SA (Ipanema Coffees), and Landsat-8 Operational Land Imager (OLI) satellite images, bands 2, 3 and 4, corresponding to Orbit / Point 219/75 from Imaging Division (DIDGI) (INPE, 2019). The images were composting in ArcGIS 10.2 (ESRI, 2014), and the accuracy was verified in field surveys, with a 95% accuracy rate. Occupancy rates for land use classes are shown in Table 1.

Table 1: Land use and occupation classes in the Ribeirão São Bento and Ribeirão José Lúcio subbasins.

Ribeirão São Bento			**Ribeirão José Lúcio**		
Land use	Area (ha)	Area (%)	Land use	Area (ha)	Area (%)
Access roads	19.88	5.97	Access roads	80.20	5.91
Facilities	1.17	0.35	Facilities	18.18	1.22
Coffee	147.74	43.55	Coffee	543.94	40.26
Native forest	94.46	27.82	Native forest	669.01	49.35
Pasture	75.95	22.31	Pasture	34.05	2.52
	----	----	Eucalyptus	23.18	1.72
TOTAL	332.92	100	TOTAL	1355.39	100

The altitudes range from 893 to 1,339 m and 849 to 1,096 m for the Ribeirão José Lúcio and Ribeirão São Bento sub-basins, respectively (Fig. 2). The digital elevation model (DEM), with spatial resolution of 12.5 m, was made from the contours extracted from the topographic map of Varginha (IBGE, 1979) and São Lourenço (IBGE, 1971), with the ArcGis 10.2 tool to Raster (ESRI, 2014).

The slope map was generated (Figure 2) using the DEM by the ArcGis 10.2 Slope tool (ESRI, 2014). The relief units were classified according to EMBRAPA (2011), in flat (0-3%), slightly rolling (3-8%), rolling (8-20%), strongly rolling (20-45%) and mountainous (45-75%) relief. In both subbasins, there was a predominance of rolling and strongly rolling relief (Figure 2).

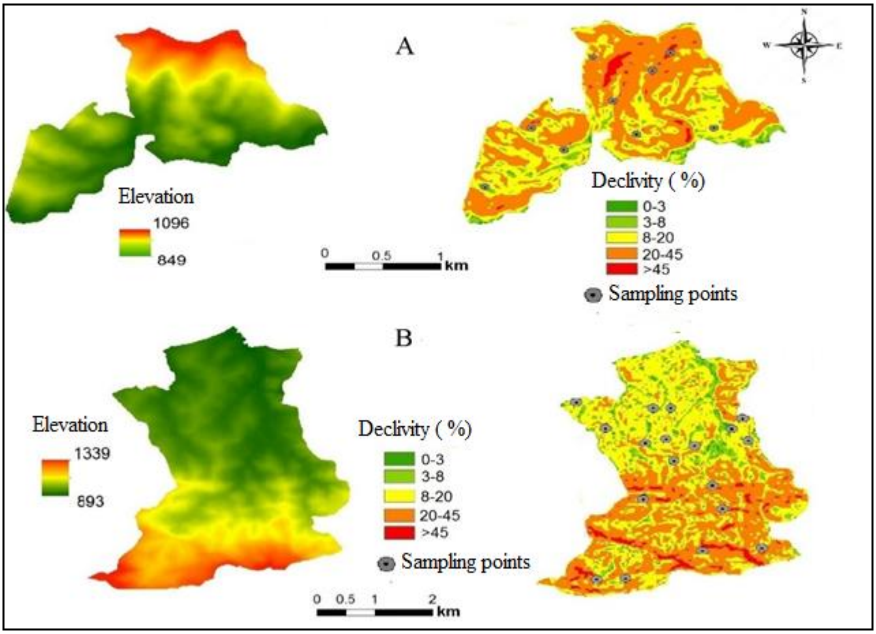

Figure 2: Digital Elevation Model (DEM) and Declivity maps in the Ribeirão São Bento (A) and Ribeirão José Lucio (B) subbasins in the respective Cambuquira and Conceição do Rio Verde Municipalities, Minas Gerais state, Brazil.

The digital soil map (Figure 3) was elaborated from the Minas Gerais State Soil Map in the ArcGis 10.2 (ESRI, 2014), on a scale of 1: 650.000 (UFV *et al.*, 2010) mutually with field surveys. We considered the relief as a base attribute of soil differentiation (McBratney *et al.*, 2003).

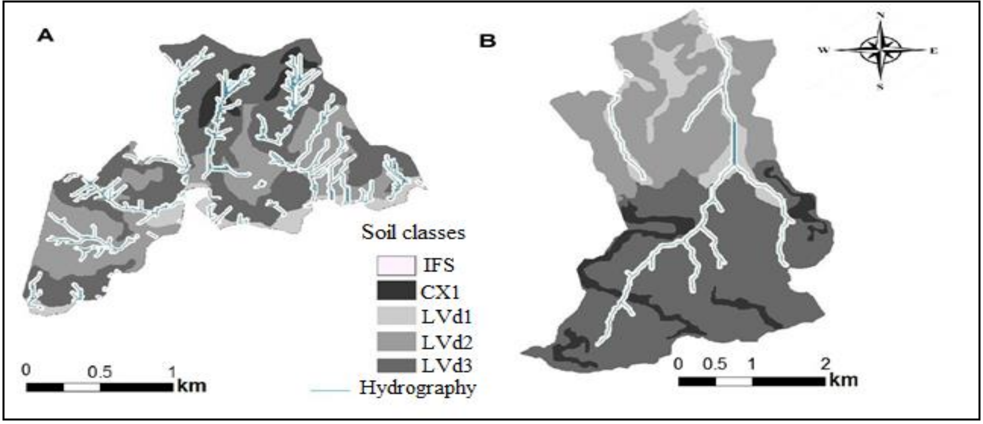

Figure 3: Digital soil maps: dystrophic red Latosol in a flat to slightly rolling relief (LVd1), dystrophic red Latosol in a rolling relief (LVd2), dystrophic red Latosol in a strongly rolling relief (LVd3), indiscriminate floodplain soils (IFS) and Haplic Cambisol (CX1) in the Ribeirão São Bento (A) and Ribeirão José Lucio (B) subbasins in the respective Cambuquira and Conceição do Rio Verde Municipalities, Minas Gerais State, Brazil.

The soils of the Ribeirão São Bento and Ribeirão José Lúcio sub-basins were classified as Latossolo Vermelho Distrófico in flat to slightly rolling reliefs (LVd1), rolling (LVd2), strongly rolling (LVd3); Cambissolo (CX1) in mountainous relief and indiscriminate lowland soils (IFS), according to the Brazilian Soil Classification System (Santos *et al.*, 2013) (Table 2).

Table 2: Soil classes, Ribeirão São Bento and Ribeirão José Lúcio subbasins.

Ribeirão São Bento			**Ribeirão José Lúcio**		
Soil classes	Area (ha)	Area (%)	Soil	Area (ha)	Area (%)
CX1	7.59	2.27	CX1	94.10	6.94
LVd1	20.86	6.26	LVd1	121.16	8.88
LVd2	108.11	32.47	LVd2	411.90	30.43
LVd3	151.56	45.55	LVd3	676.03	49.87
IFS	44.80	13.45	SIV	52.20	3.90
TOTAL	332.92	100	TOTAL	1355.39	100

CX1 = Haplic Cambisol; LVd1 = dystrophic red Latosol in a flat to slightly rolling relief; LVd2 = dystrophic red Latosol in a rolling relief; LVd3 = dystrophic red Latosol in a strongly rolling relief; IFS = indiscriminate floodplain soils.

Field sampling

Soil samples were collected based on land use and relief classes in 9 points at the Ribeirão José Lúcio subbasin and 18 points at the Ribeirão São Bento subbasin (Figure 2). We collect three types of samples on the surface (0 to 20 cm) and subsurface (20 to 40 cm) soil layers: disturb, undisturbed by the clod method, and undisturbed with a cylindrical sampler (volume 92.53 cm^3 and depth 5 cm).

The following analyses were performed: particle size distribution with and without NaOH (Bouyoucos *et al.*, 1962 ; Blake *et al.*, 1986); organic matter (MO) by oxidation with $Na_2Cr_2O_7$ 2 mol L^{-1} + H_2SO_4 5 mol L^{-1}; pH with KCl and $CaCl_2$ - 1: 2.5 ratio; sum of exchangeable bases (SB); soil density by the volumetric ring method; cationic exchange capacity at pH 7.0 (CEC-T) and effective cationic exchange capacity (CEC-t); aluminum saturation index (m), remaining phosphorus (P-rem), exchangeable Ca-Mg-Al with 1 mol L^{-1} KCl extractor, H + Al with SMP extractor; available phosphorus (P) by the colorimetric method using ascorbic acid; base saturation index (V%); flocculation index and water dispersed clay by the pipette method (Zhang, 1997); aggregate stability with weighted average diameter (MPD) and geometric mean diameter (DMG) calculation by wet sieving method and soil porosity with total pore volume calculation EMBRAPA (2011). The soil permeability variable was obtained in the field, from three replicates for each soil class with a Mini Disk Decagon Devices infiltrometer adjusted for the suction rate of 2 cm Zhang (1997). The moist color was visually classified according to the Munsell (2012) classification.

Revised Universal Soil Loss Equation

Soil loss rates at the study areas were calculated by the RUSLE (Equation 1) (Renard *et al.*, 1997).

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

Where: A is a mean annual soil loss, Mg ha^{-1} $year^{-1}$; R is the rainfall erosivity factor, MJ mm ha^{-1} h^{-1} $year^{-1}$; K is the soil erodibility factor, Mg h MJ^{-1} mm^{-1}; LS is the topographic factor expressing slope and ramp length (dimensionless); C is the factor for land use and management (dimensionless), and P is the factor for conservation practices (dimensionless) (Wischmeier and Smith, 1978).

The R factor was obtained from the rainfall erosivity map for the southern Minas Gerais state, with values ranging in the two areas from 5,145 to 7,776 MJ mm ha^{-1} h^{-1} $year^{-1}$ with an average of 6,500 MJ mm ha^{-1} h^{-1} $year^{-1}$ (Aquino *et al.*, 2012). The K factor represents soil resistance to erosion. To Cambisol this parameter was calculated by the indirect method of Bouyoucos (1962) (Equation 2) and to the Latosols by the indirect method of Silva *et al.* (1999) (Equation 3).

$$K = [(\%\ sand + \%\ silt) / (\%\ clay)] / 100 \qquad \text{(Equation 2)}$$

Where: K: average soil erodibility (Mg ha-1 MJ-1 mm-1); % sand, % silt, and % clay = percentages of the respective fractions of horizon A. The description and parameter values of Equation 2 are described in Table 3.

Table 3. Soil resistance to erosion (K) to Cambisol, according to Equation 2.

Factor			Ribeirão São Bento			
			% sand	% silt	% clay	K
		CX1 Horizon A	70	11	19	0.043
K	Erodibility		Ribeirão José Lúcio			
		CX1 Horizon A	67	16	17	0.048

Cambisol (CX1).

$$Y = -3{,}89 \times 10^{-2} + 5{,}11 \times 10^{-3} X_{14} - 1{,}25 \times 10^{-2} X_{15} + 5{,}41 \times 10^{-3} X_{16} - 7{,}27 \times 10^{-3} X_{18} + 5{,}33 \times 10^{-2} X_{33} + 3{,}21 \times 10^{-5} X_{34} - 5{,}66 \times 10^{-5} X_{36} + 8{,}33 \times 10^{-4} X_2 - 1{,}17 \times 10^{-2} X_4 + 1{,}53 \times 10^{-2} X_{13} \quad \text{(Equation 3)}$$

Note: The description and parameter values of Equation 3 are described in Table 4. The values of the variables were obtained based on soil samples collected from the native forest.

Table 4. Soil resistance to erosion (K) to Latosols.

Param.	**Description**	**Ribeirão José Lúcio**			**Ribeirão São Bento**		
		Soil Classes			Soil Classes		
		LV1	LVD2	LVD3	LVD1	LVD2	LVD3
Y	K	0.015	0.023	0.022	0.029	0.025	0.019
X_2	CEC-T pH 7.0 ($\text{cmol}_c\ \text{kg}^{-1)}$	6.490	9.170	8.238	13.315	11.086	5.120
X_4	pH = pH KCL - pH H_2O (dim)	-1.430	-0.710	-0.908	-0.820	-0.749	-0.753
X_{13}	KI relation(dim)	1.330	1.330	1.330	1.330	1.330	1.330
X_{14}	MSM Munsell (dim)	2.000	3.000	3.000	3.000	3.000	3.000
X_{15}	drainage (dim)	4.000	4.000	4.000	4.000	4.00V0	4.000
X_{16}	Structure degree (dim)	2.000	3.000	2.000	2.000	2.000	2.000
X_{18}	Structure shape (dim)	3.000	3.000	3.000	3.000	3.000	3.000
X_{33}	(TPV) ($dm^3\ dm^{-3}$)	0.628	0.608	0.607	0.600	0.619	0.645
X_{34}	Flocculation index (dim)	0.545	0.614	0.508	0.400	0.353	0.273
X_{36}	AS index ($G\ KG^{-1}$)	97.673	93.600	93.600	110.300	108.579	108.358

Dystrophic red Latosol in a flat to slightly rolling relief (LVd1), dystrophic red Latosol in a rolling relief (LVd2), dystrophic red Latosol in a strongly rolling relief (LVd3), cation exchange capacity (CEC), Dimensionless (dim), Moist Soil Matrix (MSM), total pore volume (TPV); Aggregate stability (AS).

The LS topographic factor was estimated according to Moore and Burch (1986) in the ArcGIS 10.2 (ESRI, 2014) (Equation 4) from the DEM using the

Raster Calculator tool. The model was efficient in determining LS, with higher factor values associated with steep slopes and more intense flows. The LS factor range from 0 to 238, with an average of 16.44 and 0 to 617, with an average of 7.28, for the Ribeirão São Bento and Ribeirão José Lúcio subbasins, respectively.

$$LS=\left(\text{Slope Length}\cdot\frac{12.5}{22.13}\right)^{0.4}\cdot\left(0.01745\cdot\frac{\text{Slope in Degree}}{0.0896}\right)^{1.4}\cdot 1.4 \qquad \text{(Equation 4)}$$

Where: LS = topographic factor (dimensionless); 12.5 = DEM cell size.

To determine the C and P factors, we consult the specialized literature. Areas with exposed soil present the highest C values, followed by eucalyptus cultivated down the hill, coffee, degraded pasture, facilities, indiscriminate floodplain soils, and native forest (Table 5). The higher P factor was found in degraded pasture and exposed soils, while the lowest value found in the native forest was due to the dense vegetation cover (0.01). Coffee presents a P factor of 0.50 due to conservationist practices.

Table 5. Land use and management (C) and conservation practice (P) factors for the Ribeirão São Bento and the Ribeirão José Lúcio subbasins.

Land use and occupation	Factor C	Source factor C	Factor P *
Coffee (3.95 x 0.55 m)	0.135	Prochnow 2005	0.50
Degraded pasture	0.100	Roose 1977	1.00
Native forest	0.001	Silva 2016	0.01
Floodplains soils	0.004	Oliveira 2007	0.00
Facilities	0.010	Lin 2011	0.00
Eucalyptus down the hill	0.300	Martins 2010	1.00
Exposed soil	1.000	----	1.00

*Valores de P obtidos de Bertoni e Lombardi Neto (2012) e Roose (1977).

Validation

The validation of soil loss estimates was done by monitoring the annual sediment transport, according to Beskow *et al.* (2009). For this purpose, data of total solids in water and respective flow monitored from 1997 to 2010 by two hydrosedimentological stations operated by the Minas Gerais Institute for Water Resources Management (IGAM), located in the municipalities of Cambuquira (MG 473138 W and 7581539 S), and Conceição do Rio Verde (MG, 490706 W and 7572704 S). Afterwards, the annual sediment transport was calculated considering the flow of the sub-basins and the daily flow of data obtained from the National Water Agency (ANA).

The annual sediment transported was compare with the Sediment Delivery Ratio (SDR), which represents the eroded soil fraction that reaches the water bodies. The SDR value is determined according to Equation 5 Vanoni (1975).

$$\mathbf{SDR=0.473\cdot(0{,}00386102*A)^{-0.125}} \qquad \text{(Equation 5)}$$

Where SDR is Sediment Delivery Ratio (%); A is basin drainage area (ha).

Soil Loss Tolerance (T)

The T was calculated by Equation 6 (Bertol and Almeida, 2000).

$$T = h \cdot r_a \cdot m \cdot p \cdot Ds \cdot 1000^{-1} \qquad \text{(Equation 6)}$$

Where T is the soil loss tolerance (Mg ha^{-1} $year^{-1}$); h is the effective soil depth (cm), limited to 100 cm; r_a is the ratio that expresses, mutually, the effect of the textural relationship between the horizons B and A and the clay content of the horizon A; m expresses the organic matter content in the 0 - 20 cm soil depth; p is the soil permeability factor; Ds is the soil density (kg dm^{-3}); and 1.000 is the constant that expresses the time period required to wear away a soil layer of 1,000 mm thickness.

Latosols and Cambisols of the study area present an effective soil depth (h) of 1000 mm and 800 mm, respectively. The other parameters were determined according to Bertol and Almeida (2000), using the soil analyses results. Both subbasins present a r_a of 1 and an m and p of 0.7, with soil permeability classified as slow. Soil density of Latosols and Cambisols was, respectively, 1.23 kg dm^{-3} and 1.21 kg dm^{-3} for Ribeirão Jose Lucio and Ribeirão São Bento subbasins.

RESULTS AND DISCUSSION

The total soil loss of the Ribeirão São Bento subbasin was 1,032 Mg $year^{-1}$, while the Ribeirão José Lúcio subbasin presents a loss of 5,014 Mg $year^{-1}$. The sediment delivery ratio (SDR) was 0.045 and 0.38 indicating that 45% and 38% of eroded sediments in the respective Ribeirão São Bento and Ribeirão José Lúcio subbasins reach the water bodies. Thus, considering the SDR, the average soil loss estimated by RUSLE was 1.41 and 1.22 Mg $year^{-1}$ ha^{-1} (Table 6).

We found errors of 0.19 Mg $year^{-1}$ ha^{-1} (15.57%) and 0.25 Mg $year^{-1}$ ha^{-1} (19.82%) comparing RUSLE results with the annual sediment transported calculated using field data (Table 6).

According to Pandey (2007), errors smaller than 20% allow the validation of the water erosion models. Thus, the results generated by RUSLE illustrate the satisfactory efficiency of the method employed.

Table 6. Soil loss estimate by RUSLE, annual sediment delivery and estimate errors.

Subbasin	Soil loss rate (Mg ha^{-1} year^{-1})	Annual sediment delivery (Mg ha^{-1} year^{-1})	Error (Mg ha^{-1} year^{-1} and %)
José Lúcio	1.41	1.22	0.19 (15.57)
São Bento	1.39	1.16	0,23 (19,82)

W_{yr} = Annual erosion; G_{yr} = real soil loss;

Areas with exposed soil and steeper slopes have the highest rates of soil loss in both sub-basins (Figure 4).

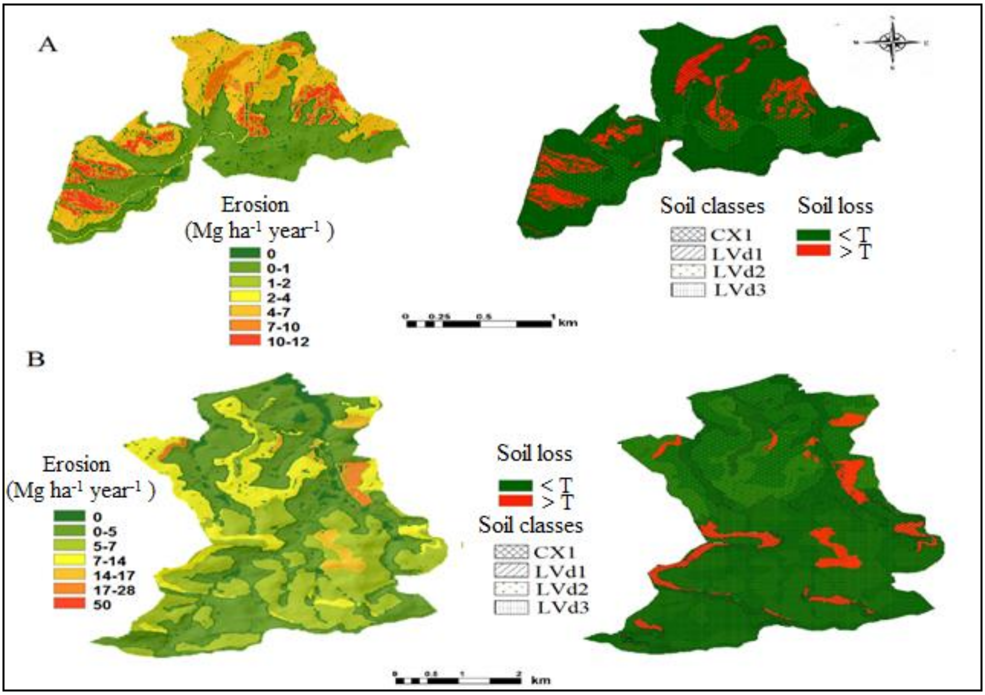

Figure 4: Soil loss rates and Soil Loss Tolerance (T) in the Ribeirão São Bento (A) and Ribeirão José Lucio (B) subbasins in the respective Cambuquira and Conceição do Rio Verde Municipalities, Minas Gerais State, Brazil.

Note: Dystrophic red Latosol in a flat to slightly rolling relief (LVd1), Dystrophic red Latosol in a rolling relief (LVd2), Dystrophic red Latosol in a strongly rolling relief (LVd3).

As expected, due to the greater fragility of Cambisols, the sediment generation rates in each class of land use showed that Cambisols are more susceptible to erosion compared to Latosols (Bertol and Almeida, 2000) (Table 7).

The soil loss rate estimated in the native forest was 0.01 Mg ha^{-1} year^{-1}, similar to Silva *et al.* (2007) that found soil loss rates range from 0.01 to 0.38 Mg ha^{-1} year^{-1}, in a native forest at the Rio Grande do Sul State. The low losses in native forests are due to natural conservation and the protection offered to the soil by the canopy of dense vegetation and litter.

Coffee areas presented average soil loss rates of 4.50 and 5.71 Mg ha^{-1}year^{-1} for the Ribeirão São Bento and Ribeirão José Lucio subbasins, respectively. The highest rates of erosion in coffee were found in young areas, when soil cover by the canopy of coffee trees is still low (Carvalho *et al.*, 2007). The results obtained were lower than the values observed by Silva *et al.* (1999) (10.98 Mg ha^{-1} year) for Dystrophic Red-Yellow Latosol. These results are due to the conservation practices adopted in the coffee areas, with consequent lower P factor value (0.5).

Table 7. Soil losses by the land use and occupation classes in the Ribeirão São Bento and the Ribeirão José Lucio subbasins.

	Ribeirão São Bento			**Ribeirão José Lucio**		
Land use	Area (ha)	Area (%)	Soil loss Mg ha^{-1} year^{-1}	Area (ha)	Area (%)	Soil loss Mg ha^{-1} year^{-1}
Facilities	1.17	3.35	0.00	10.01	0.73	0.24
Coffee	147.74	43.55	4.50	538.94	39.76	5.71
Access roads	19.88	5.86	6.27	80.20	5.91	6.33
Native forest	94.46	27.84	0.10	669.01	49.35	0.24
Pasture	75.95	22.31	0.21	34.04	2.51	3.01
Eucalyptus	-	-	-	23.18	1.71	18.24
Total	332.92	100	-	1355.39	100	-

Eucalyptus showed the highest rate of soil loss among the land use classes (Table 7), due to the young age of the plants, which provides low canopy protection against erosion. The T limits determined for the Ribeirão São Bento and the Ribeirão José Lúcio subbasins were 8.3, 7.5, 7.1 and 6.7 Mg ha^{-1} year^{-1}, and 6.5, 8.5, 7.5 and 5.5 Mg ha^{-1}year^{-1} for the LVd1, LVd2, LVd3, and CX1, respectively. Ribeirão São Bento subbasin has 13.16% of the area with losses above T, while 7.9% of the Ribeirão José Lúcio subbasin area exceeded the T limits.

The T results obtained are below those found by Bertol and Almeida (2000) for Latosols from Santa Catarina State (10.62 to 12.50 Mg ha^{-1} year^{-1}) and São Paulo State (9.60 to 15.00 Mg ha^{-1} year^{-1}) according to Bertoni and Lombardi Neto (2012). This difference may be due to Bertol and Almeida (2000) method considering more attributes related to the soil formation factors in the T estimation.

Determining the T is quite difficult due to the difficulties in calculating soil formation rates. For this reason, soil properties, such as organic matter, water permeability in the soil and the textural relationship between horizons B and A, which indirectly reflect the rates of soil formation, are used to define T. Conceptually, every soil has a limit T, which is related to your training rate. Thus, T calculations are complementary to water erosion estimates and allow a more accurate assessment of soil degradation status

Areas with soil losses above T should be prioritized in the adoption of conservation management practices, seeking to minimize water erosion, and ensuring the long-term sustainability of agricultural production. Better management practices such as terracing, level planting, and cover crops between the coffee lines could mitigate the erosion rates and decrease the runoff, consequently provide the conservation of watercourses, and improve the fertilizer use efficiency, which reduces the production costs (Bertoni and Lombardi Neto, 2012).

Considering the importance of coffee growing in high altitudes and steep areas in the south of Minas Gerais State, the results showed that the adoption of conservationist management practices provide low soil loss rates and contribute to the sustainability of coffee production. The studied subbasins presented distinct values of soil loss susceptibility but similar characteristics in the places most susceptible to erosion. The RUSLE model allowed the identification of areas with soil losses above the limits of T, especially in steep areas with coffee cultivation. Thus, it is an alternative tool for planning land use and management to promote sustainable agricultural systems.

CONCLUSIONS

Ribeirão São Bento and Ribeirão José Lúcio subbasins soil losses ranged from 0.01 to 28.45 Mg ha^{-1} year^{-1}, with an average of 1.41 and 1.22 Mg year^{-1}, respectively. The average soil loss in the coffee cultivation areas was 5.1 Mg ha^{-1} year^{-1}.

Revised Universal Soil Loss Equation modeling of water erosion showed higher losses rates in areas with steeper slopes and without conservation practices. The areas with soil loss above the tolerance limits should be a priority for the adoption of mitigation measures.

The RUSLE model is a fast, simple, and inexpensive tool that contributes to the assessment of soil conservation in hydrographic subbasins.

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