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ESTIMATE OF WATER EROSION IN COFFEE GROWING AREAS IN SERRA DA MANTIQUEIRA, MINAS GERAIS STATE, BRAZIL

Abstract

Water erosion is a major cause of soil degradation worldwide. This natural phenomenon has been continually accelerated by anthropogenic activities, with constants increase of soil losses. The main objective of this study was to apply the Modified Universal Soil Loss Equation (MUSLE) model to estimate soil loss in rainy events during one year period. The total study was conducted between August 2017 and July 2019 in coffee growing areas located in the Serra da Mantiqueira, Southern Minas Gerais, Brazil. Most of the factors used for the MUSLE equation were determined from Geographic Information Systems. The results showed that soil losses ranged from 53.40 to 28.37 Mg in both areas depending on the land use and 33.12 and 23.82 Mg related to the soil classes. The largest soil losses were estimated to exposed soils in eucalyptus without conservationist practices, in the highest slopes and in Haplic Cambisol (CX). It was concluded that the conservation management practices correlated to anthropic activities adopted in the coffee crop contributed to the reduction of soil losses and maintenance of edaphic conditions.

Keywords: Soil losses, Prediction models, Modified Universal Soil Loss Equation, MUSLE, Brazil.

INTRODUCTION

Coffee is one of the most important natural products of international trade. About 63% is produced in Central and Southern America, 30% in Asia and 7% in

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Africa (Potts, 2014). In Brazil, Minas Gerais State accounts for most of the productive area, with about 1.23 million hectares (CONAB, 2019) and gross production of 30,735,800 bags of coffee. Minas Gerais Southern is responsible for a large part of this production, with about 655,221 hectares destined for planting (CONAB, 2019).

Despite its socioeconomic relevance, coffee production in the Southern Minas Gerais is also characterized by extensive land use, inadequate edaphic management, inefficient crop rotation, misuse and lack of herbicide alternation and non-application of related plans the Integrated Management of Pests and Diseases - MIPD (Giunti, 2017). These elements are responsible for gradually intensifying erosion processes (Bertoni and Lombardi Neto, 2014, Dechen *et al.*, 2015), increasing losses of soil, water, organic matter, nutrients and agrochemicals, which deplete arable land and harm the sustainability of agricultural systems (Oliveira *et al.*, 2012).

Over time, simulation models of erosive processes have been developed and improved. One of these models is the Modified Universal Soil Loss Equation - MUSLE (Williams, 1975), capable of estimating the soil losses that occur in a given period or after isolated rain events. The MUSLE data entry is simple and the results can be obtained quickly, based on the runoff, the peak flow, the edaphic properties, the terrain characteristics and the adopted management practices.

This study estimated the soil losses in Latosols and Cambisols, with a predominance of coffee cultivation, in high altitudes of the Serra da Mantiqueira, Southern Minas Gerais, aiming to identify the areas with the greatest soil losses and to indicate measures mitigates of erosive processes.

MATERIAL AND METHODS

The study area is the Rio Verde Farm, located at Ribeirão José Lúcio hydrographic Subbasin, a tributary of the Rio Verde, located in the Conceição do Rio Verde Municipality, Minas Gerais State, Brazil. The area has 1,355.39 ha and is located at coordinates 7575500 to 7570000 N and 479000 to 483800 E, Datum SIRGAS 2000, Zone 23 K (Figure 1).

Figure 1: Study area location map

The maps were produced in ArcGIS 10.2 (ESRI, 2014). The digital land use and occupation map was produced from images Landsat-8 TM (Thematic Mapper) satellite, bands TM6, TM5, and TM4, orbit 219/75, obtained from the United States Geological Survey (USGS, 2017); images from Google Earth and maps provided by Ipanema Coffees were also used. The classification of land use and occupation was based on mappings by Ipanema Coffees, visually by analyzing satellite images and subsequent verification and correction in the field (Figure 2).

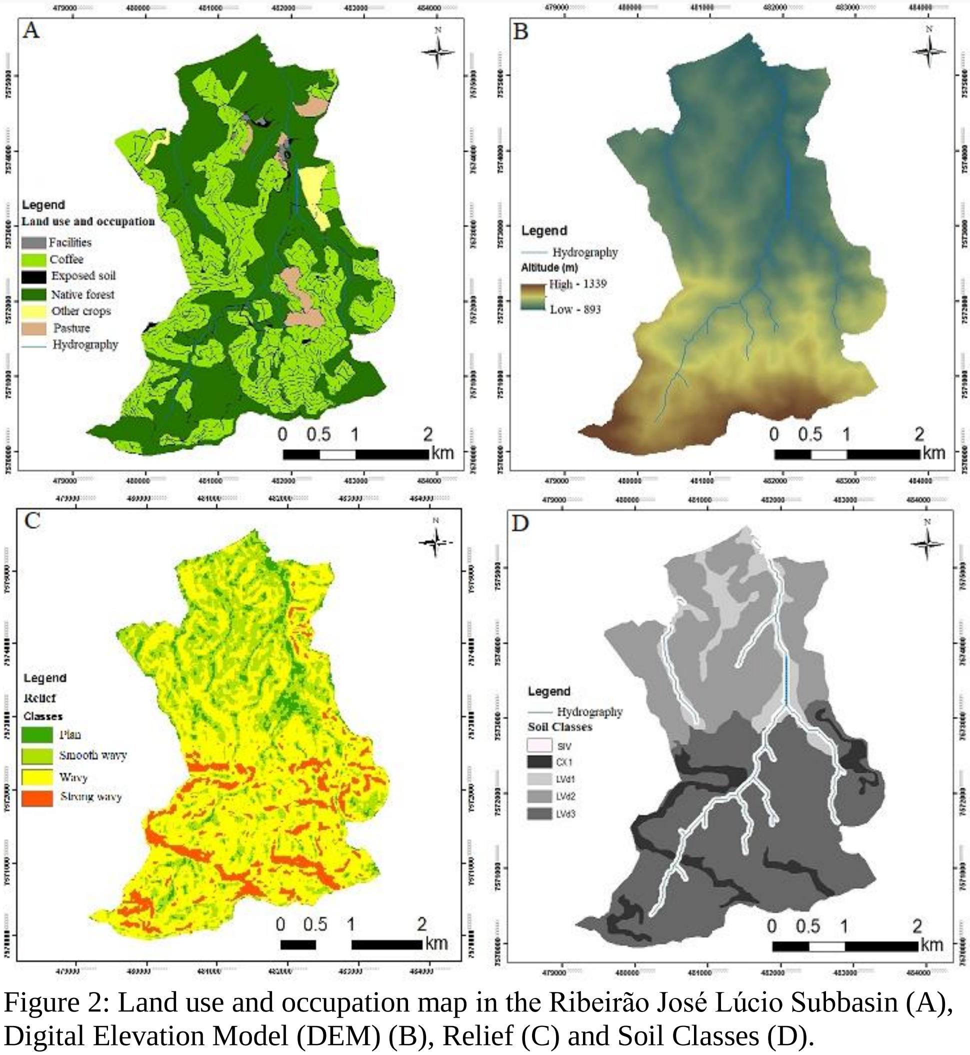

Figure 2: Land use and occupation map in the Ribeirão José Lúcio Subbasin (A), Digital Elevation Model (DEM) (B), Relief (C) and Soil Classes (D).

Notes: Other crops refer to eucalyptus, mahogany and macadamia.

SIV = Indiscriminate Lowland Soils; CX1 = Haplic Cambisol; LVd1 = Dystrophic Red Latosol in flat and smooth undulated relief; LVd2 = Dystrophic Red Latosol in undulated relief; LVd3 = Dystrophic Red Latosol in strong undulated relief.

The digital elevation model (DEM) was generated from the interpolation of the contour lines of the Varginha Topographic Chart (IBGE, 1979). The value of each cell (pixel) was 12.5 x 12.5 m.

The terrain slope map was generated by the Slope tool applied in the MDE (ESRI, 2014). The relief of the Subbasin was classified according to EMBRAPA (2018).

The digital map of soil classes was produced based on the Minas Gerais State Soil Map, scale 1:650,000 (UFV *et al*., 2010). The relief classes present in the slope map guided the definition of the soil classes (McBratney *et al*., 2003), together with the morphological field descriptions and physical and chemical analyzes carried out in the Soil Laboratories of the Department of Soil Science of the Federal University of Lavras.

From the maps, 18 points were selected for soil collections. At each sampling point, collections were carried out at depths 0 – 20 cm and 20 – 40 cm. Deformed, undisturbed clod-shaped and undisturbed samples were collected with a cylindrical sampler with a volume of 92.53 cm^3 and a height of 5 cm. The soils were described according to Santos *et al*. (2005).

Soil loss in watersheds was based on the MUSLE (Williams, 1975) (Eq. 1).

$$A = 11.8 \times (D \times Q_p)^{0.56} \times K \times LS \times C \times P \tag{1}$$

where: A - represents soil losses (Mg); 11.8 and 0.56 - original MUSLE adjustment coefficients (dimensionless); D - runoff or surface runoff (mm); Qp - peak flow (m^3 s^{-1}); K - average erodibility of the basin soil (Mg h MJ^{-1} mm^{-1}); LS - topographic factor (dimensionless); C - land use and management factor (dimensionless); P - conservation practices factor (dimensionless).

To estimate the K factor of soils, the model 3 (Silva *et al*., 1999) was adopted to classified as Latosols, which has the r^2 de 0.91 and adopts easily measured variables. The K factor of model 3 was estimated by the equation below: (Eq. 2).

$$Y = -3.89\times10^{-2} + 5.11\times10^{-3}X_{14} - 1.25\times10^{-2}X_{15} + 5.41\times10^{-3}X_{16} - 7.27\times10^{-3}X_{18} + 5.33 \times10^{-2}X_{33} + 3.21\times10^{-5}X_{34} - 5.66\times10^{-5}X_{36} + 8.33\times10^{-4}X_2 - 1.17\times10^{-2}X_4 + 1.53\times10^{-2}X_{13}$$

$$r^2 = 0.91^{**} \tag{2}$$

The K factor for soils classified as Cambisols was estimated by the indirect method for the two depths (0 - 20 cm and 20 - 40 cm) through the expression of Bouyoucos (Bertoni and Lombardi Neto, 2014). The model is described below: (Eq. 3).

$$K = [(\%sand + \%silt)/(\%clay)]/100 \tag{3}$$

where: K - average soil erodibility (Mg h MJ^{-1} mm^{-1}); % sand, % silt and % clay - percentages of the respective fractions for each depth (Table 1 and 2).

Table 1. Erodibility values (K) and the variables used

Variable	Description	LVd1	LVd2	LVd3	CX1
K	Erodibility (Mg ha MJ^{-1} mm^{-1})	0.0227	0.0149	0.0218	-
X_2	Soil cation exchange capacity at pH 7.0 (cmolc kg^{-1})	6.49	9.17	8.23	8.18
X_4	ΔpH = pH KCl – pH H_2O (adimensional)	-1.43	-0.71	-0.90	-0.95
X_{13}	Ki Relation (adimensional)	1.33	1.33	1.33	-
X_{14}	MSM Munsell (adimensional)	2.00	3.00	3.00	3.00
X_{15}	Soil profile drainage code (dimensionless)	4.00	4.00	4.00	4.00
X_{16}	Structure grade code (adimensional)	2.00	3.00	2.00	2.00
X_{18}	Structure shape code (adimensional)	3.00	3.00	3.00	3.00
X_{33}	Total pore volume (dm^3 dm^{-3})	0.62	0.60	0.60	0.61
X_{34}	Flocculation index (dimensionless)	0.54	0.61	0.50	0.42
X_{36}	Aggregate instability index (g kg^{-1})	97.60	93.60	93.60	92.05

Notes: ΔPh - difference between pH KCl and pH H_2O; pH KCl - pH determined in potassium chloride solution; pH H_2O - pH determined in water solution; Ki Relation - molecular ratio between SiO_2 and Al_2O_3. Source: Silva *et al*. (1999).

Table 2. Erodibility values (K) of Cambisols and the variables used

Variable	Description	Class	%sand	%silt	%clay	K
K	Erodibility	CX1	47	26	27	0.0270
K	Erodibility	CX2	35	30	35	0.0185

Notes: CX1 - Haplic Cambisol in depth 0 – 20cm; CX2 - Haplic Cambisol in depth 20 – 40cm. Source: Mannigel *et al*. (2002).

The topographic factor LS was estimated according to the methodology of Moore and Burch (1986) in ArcGIS 10.2. from the DEM Topodata, with 12.5 m resolution. The expression of Moore and Burch (1986) was inserted in the Raster Calculator function (Eq. 4).

$$LS = (\text{Slope Length} * 12.5/22.13)^{0.4} \times (0.01745 * \text{Slope Degree}/0.0896)^{1.4} \times 1.4 \quad (4)$$

where: LS - topographic factor (dimensionless); Slope Length - flow accumulation (dimensionless); 12.5 - DEM cell size; Slope Degree - slope in degrees. C Factor and P values were obtained from the specialized literature (Table 3).

Table 3. C Factor and P values for verified uses and managements

Land use and occupation	C Factor	Source C Factor	P Factor
Coffee (3,95 x 0,55 m)	0.13	Prochnow *et al*. (2005)	0.50
Degraded pasture	0.10	Panagos *et al*.(2015a)	1.00
Native forest	0.01	Silva *et al*. (2016)	0.01
Facilities	0.01	Panagos *et al*. (2015a)	1.00
Eucalyptus down the hill	0.30	Martins *et al*. (2010)	1.00
Exposed soil	1.00		1.00

Notes: P values obtained from Bertoni and Lombardi Neto (2014) and Panagos *et al*. (2015b). Only data referring to eucalyptus were used for the land use and occupation class “other crops”.

To calculate the runoff (D) the abstraction method (SCS, 1972) was used through Equation 5 below: (Eq. 5).

$$D_{ij} = \frac{(P - 0.2 \times Sa)^2}{(P + 0.08 \times Sa)} \qquad (5)$$

where: Dij - runoff volume (per pixel) for a given rainy event (mm); P - maximum precipitation volume (mm); Sa - soil water retention parameter obtained from the land surface characteristics.

The parameter Sa (Equation 6) was determined as a function of the relationship between the parameters: (a) soil class, land use and occupation, slope and adopted management; (b) time, as a function of soil water content. The time is derived from the Curve Number (CN) index (Eq. 6).

$$\mathrm{Sa} = 254\left(\frac{100}{\mathrm{CN}-1}\right) \qquad (6)$$

Soil hydrological groups were obtained from Sartori *et al*. (2005). LVd belongs to Hydrological Group A (very deep, high infiltration rate, more resistant to erosion and clayey texture); CX1 belongs to Group C (deep or shallow, reduced infiltration rate, less resistant to erosion and sandy texture).

Peak flow and sediment rate (Qp) were quantified for one year. Peak flow (Qp) was measured directly in the Parshall gutter installed in the watercourse of the Ribeirão José Lúcio Subbasin. For surface runoff, values were assigned for each pixel in the area. Soil loss maps were produced every 3 months.

RESULTS AND DISCUSSION

The values of the areas referring to land use and occupation, soil classes and relief are presented in Table 4.

Table 4. Land use and occupation, soil classes and relief values

Land use and occupation

Type	Area (ha)	Area (%)
Exposed soil	80.20	5.91
Facilities	18.18	1.22
Coffee	543.94	40.26
Native forest	669.01	49.35
Pasture	34.05	2.52
Other crops	23.18	1.72
TOTAL	**1,355.39**	**100**

Soil classes

Tipe	Area (ha)	Area (%)
CX1	94.10	6.94
LVd1	121.16	8.88
LVd2	411.90	30.43
LVd3	676.03	49.87
SIV	52.20	3.90
TOTAL	**1,355.39**	**100**

Relief classes

Relief	Slope (%)	Area (ha)	Area (%)
Plan	0 – 3	80.22	5.97
SW	3 – 8	359.78	26.78
Wavy	8 – 20	771.09	57.40
StW	20 – 45	132.10	9.45
TOTAL		**1,355.39**	**100**

Notes: SW – smooth wavy relief ; StW – strong wavy relief.

CX1 obtained the highest erodibility values due to the high sand fraction indexes. LVd2 had the lowest erodibility values due to the high content of organic matter (X_3), the lowest coarse sand content dispersed in water (X_{27}), the highest clay content dispersed in water (X_{32}) and the second highest value of the index of aggregate stability (X_{36}).

K values were lower than those found by Demarchi and Zimback (2014) for LVd. This fact is due to the difference in the attributes of each soil and also to the methodology used to obtain the K factor, since these authors used the methodology of Mannigel *et al*. (2002), which considers only the texture to obtain erodibility and overestimates the final values of K.

The K values for CX1 were higher than the values found by Silva *et al*. (1999), which was determined to be 0.0355. In the Ribeirão José Lúcio Subbasin the soils are derived from quartzites and metavolcanosedimentary sequences.

Quartzites produce sandy soils and this is visible in steep reliefs. In the lower altitudes, with the metavulcanosedimentary sequences, it is more clayey. This variation is due to the different procedures for obtaining the factor and the distinction of sand values can be highlighted, having lower contents in the work by Silva *et al*. (1999).

The LS factor ranged between 0 and 617.29 and an average value of 7.28. The model proved to be efficient in determining the LS factor, as the highest values were found in areas with higher slopes and more intense flows. In the areas where the ramp length is greater, the average was high, however the values were close. The highest value of C was obtained in the exposed soil, (C = 1.00), followed by eucalyptus downhill (C = 0.30). Coffee obtained a value of 0,13. The lowest value of C was obtained in the urbanized area; however, erosion is not calculated at this location, only surface runoff. The native forest had a value of 0.01. Regarding the P factor, the highest values were obtained in degraded pasture, exposed soil and eucalyptus downhill (P = 1.00). The lowest value was found in native forest (0.01), while coffee planted in contour lines had an intermediate value (0.50).

The native forest has the lowest CN values, while the highest values were obtained in the exposed soil. This fact occurs due to the vegetation cover, which attenuates runoff, while the impermeability of the soil increases runoff.

Table 5. Rainfall events analyzed over a one-year period

Moment	Date	Precipitation Index (mm)	Q (m^3)	Qp (m^3/s)	Y – MUSLE (Mg)
1	02/22/2018	33 mm	1,860.68	0.040	13.876
	03/17/2018	46 mm	2,398.96	0.083	22.915
	03/28/2018	30 mm	1,759.33	0.039	12.134
2	05/02/2018	17 mm	989.11	0.022	6.239
	06/28/2018	9 mm	443.45	0.009	6.641
	07/07/2018	11 mm	556.97	0.013	12.898
3	09/03/2018	26 mm	1,429.08	0.026	21.337
	11/11/2018	19 mm	1,397.65	0.020	16.032
	11/25/2018	38 mm	2,289.06	0.045	20.430
4	12/02/2018	51 mm	2,464.21	0.052	31.038
	01/05/2019	40 mm	2,105.73	0.041	24.872
	01/23/2019	28 mm	2,090.08	0.033	25.631

where: Q – surface runoff or runoff; Qp - peak flow and Y - soil loss

The runoff map is showed in Figure 3 and the estimated values of soil losses according to land use and occupation are listed in Table 6.

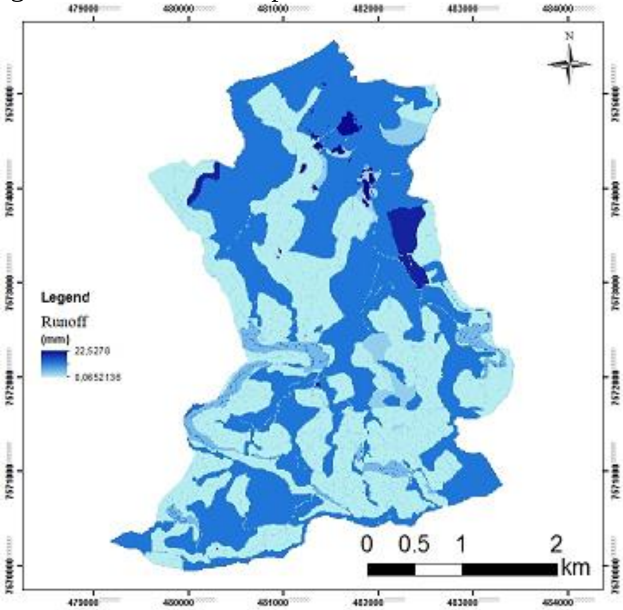

Figure 3. Runoff map in the Ribeirão José Lúcio Subbasin

Table 6. Subbasin soil losses according to land use and occupation

	Moment 1		Moment 2	
Land use and occupation	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**
Exposed soil	10.66	0.15	7.94	0.09
Coffee	13.71	0.02	8.33	0.01
Native forest	4.09	0.01	2.54	0.01
Pasture	10.91	0.37	6.66	0.19
Other crops	19.88	0.88	10.07	0.43
TOTAL	53.40	0.29	35.54	0.15
	Moment 3		Moment 4	
Land use and occupation	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**
Exposed soil	9.34	0.14	12.75	0.17
Coffee	10.98	0.02	15.02	0.03
Native forest	3.66	0.01	4.44	0.01
Pasture	9.03	0.25	11.96	0.40
Other crops	17.55	0.60	20.22	0.95
TOTAL	50.56	0.26	64.39	0.35

According to land use and occupation, the total land loss estimated by MUSLE in the Ribeirão José Lúcio Subbasin was variable in the 4 moments. The highest soil losses were obtained at time 4, which corresponds to the season with the highest rainfall. The highest average soil losses were obtained in other crops. This fact is due to the large spacing between the eucalyptus trees, as they are at an early stage of development, the high slope at the cultivation site and mainly due to the absence of conservation management.

The native forest favored infiltration and reduced surface runoff, attenuating the carrying of soil particles and consequent transport of sediments. This result is evidenced in another study (Bolleli *et al*., 2020), since the organic matter in the edaphic composition attenuates surface runoff and favors water infiltration. Coffee cultivation also had low soil loss values, demonstrating the efficiency of crops in mitigating erosive processes and maintaining soil properties, as demonstrated in Tavares *et al*. (2019).

The native forest occupies approximately 49.35% of the area, and has very low estimated soil loss values, stressing once again the importance of vegetation cover in reducing the erosive process (Lense *et al*., 2020). Compared to other works, the average soil loss values were higher than those obtained by Silva *et al*. (2016) due to the steeper relief. Soil losses related to the exposed soil were low, as this is located mainly between the coffee planting rows, a fact that contributes to the reduction of runoff. Soil loss values according to soil classes are shown in Table 7.

Table 7. Soil losses according to soil classes

	Moment 1		Moment 2	
Soil Classes	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**
CX1	13.90	0.17	10.55	0.13
Lvd1	12.98	0.12	9.61	0.10
Lvd2	7.77	0.02	5.73	0.01
LVd3	5.08	0.01	4.17	0.01
*SIV	-	-	-	-
TOTAL	37.73	0.38	28.46	0.25

	Moment 3		Moment 4	
Soil Classes	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**	**Total Loss (Mg)**	**Average Loss (Mg ha^{-1})**
CX1	12.46	0.13	15.99	0.16
Lvd1	11.55	0.11	14.21	0.13
Lvd2	6.90	0.02	7.81	0.02
LVd3	5.85	0.01	6.19	0.01
*SIV	-	-	-	-
TOTAL	34.76	0.33	41.20	0.42

Notes: SIV was considered sediment deposition area.

According to soil classes, the greatest total and average soil losses occurred in CX1 and the smallest in LVd3. Class CX1 is more susceptible to the erosive process due to the intrinsic attributes of this soil, such as high sand content, low clay content, and is associated with higher slopes and the presence of greater trails.

According to Gelagay and Minale (2016), the highest average soil losses were also found in high slope locations for the Koga watershed in Ethiopia. This fact can be verified in Oliveira *et al*. (2012), who demonstrated the direct relationship between precipitation, runoff and sediment transport. These authors used the ArcMUSLE (Zhang *et al*., 2009) to assess the production of sediment and consequent loss of soil. Dechen *et al*. (2015) also found that the higher the percentage of soil cover, the lower the runoff and the lower the losses of water, soil, organic matter and soil nutrients. The final maps of soil loss estimates are shown in Figure 4.

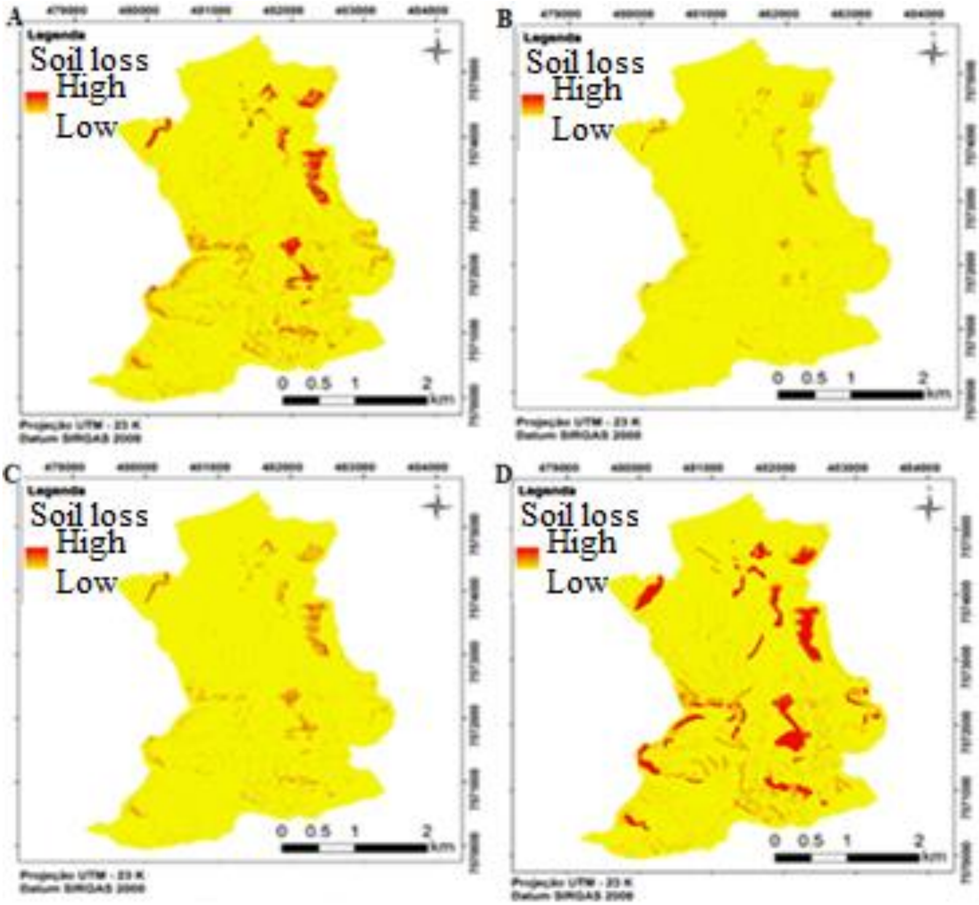

Figure 4. Estimative soil losses maps in the Ribeirão José Lúcio Subbasin, (A) Moment 1; (B) Moment 2; (C) Moment 3 and (D) Moment 4

CONCLUSIONS

The lowest estimates of total and average soil loss occurred in native forest, demonstrating the vegetation's efficiency in mitigating erosive processes. Coffee has also been shown to be directly efficient in mitigating erosive processes, especially in steeper terrain.

Class CX1 was the one that presented the highest estimates of average and total soil loss as a function of the more sandy content, the high K value and also for being inserted in the highest slopes and under the planting of other crops.

MUSLE proved to be efficient in the spatial identification of soil losses, revealing the efficiency of native forest and conservation practices adopted in the coffee plantation, such as contour and contour planting, reducing surface runoff and consequently soil losses.

Finally, it is concluded that the influence that anthropic interventions exert on the landscape is directly responsible for environmental susceptibility and the quality of resources. Because of this, studies on this bias are essential to understand and monitor soil erosion processes and the consequent sustainable management of resources.

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REFERENCES

Bertoni, J. & Lombardi-Neto, F. (2014): Conservação do solo. 9th ed. São Paulo: Ícone. 396 pp.

Bolleli, T.M., Lense, G.H.E., Santana, D.B., Moreira, R.S., Sestras, P., Spalevic, V. & Mincato, R.L. (2020): Estimates of soil losses in watershed under tropical of altitude climate in Brazil. Agriculture and Forestry, 66(1): 73–88.

CONAB - Companhia Nacional de abastecimento (2019): Acompanhamento da safra brasileira: café –5 (1) Primeiro levantamento/janeiro 2019. Brasília: Conab, 2019. (also avaliable at: https://www.conab.gov.br/info-agro/safras/cafe>).

Dechen, S.C.F., Telles, T.S., Guimarães, M.F. & Maria, I.C. de. (2015): Perdas e custos associados à erosão hídrica em função de taxas de cobertura do solo. Bragantia, 74(2): 224-233.

Demarchi, J.C. & Zimback, C.R.L (2014): Mapeamento, erodibilidade e tolerância de perda de solo na Sub-bacia do Ribeirão das Perobas. Energia na Agricultura, 29:102-114.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. (2018): Sistema Brasileiro de Classificação de Solos. 9th ed. Rio de Janeiro: Embrapa Solos. 186 pp.

ESRI - Environmental Systems Research Institute. (2014): ArcGIS Professional GIS for the desktop [computer program]. Version 10.2. Redlands, CA: Environmental Systems Research Institute.

Gelagay, H.S. & Minale, A.A. (2016): Soil loss estimation using GIS and remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. International Soil and Water Conservation Research, 4(2): 126-136.

Giunti, O.D. (2017): Café nas montanhas: caracterização da cafeicultura na área de atuação da Cooperativa Regional de Cafeicultores em Guaxupé. 3th ed. Pouso Alegre: IFSULDEMINAS, 2017. 172 pp.

IBGE - Instituto Brasileiro de Geografia e Estatística (1979): carta topográfica do Município de Varginha (FOLHA SF 23-V-D 1:250000). 2th ed. Rio de Janeiro: Secretaria de Planejamento da Presidência da República do IBGE, Diretoria de Geociência e Cartografia, Superintendência de Cartografia.

Lense, G.H.E., Moreira, R.S., Bócoli, F.A., Parreira, T.C., Teodoro, A.E.M., Spalevic, V. & Mincato, R.L. (2020): Soil organic matter loss by water erosion in a coffee organic farm. Agriculture and Forestry, 66(4): 45–50.

Mannigel, A.R., Carvalho, M.P., Moreti, D. & Medeiros, L.R. (2002): Fator erodibilidade e tolerância de perda dos solos do Estado de São Paulo. Acta Scientiarum, 24(3): 1335-1340.

Martins, S.G., Silva, M.L.N., Avanzi, J.C., Curi, N. & Fonseca, S. (2010): Fator cobertura e manejo do solo e perdas de solo e água em cultivo de eucalipto e em Mata Atlântica nos Tabuleiros Costeiros do estado do Espírito Santo. Scientia Forestalis, 38(1): 517-526.

McBratney, A.B., Santos, M.L.M. & Minasny, B. (2003): On digital soil mapping. Geoderma 117(2): 3-52.

Moore, I.D. & Burch, G.J. (1986): Physical basis of the length-slope factor in the Universal Soil Loss Equation. Soil Science Society American Journal, 50(4): 1294-1298.

Oliveira, F.P., Buarque, D.C., Viero, A.C., Merten, G.H., Cassol, E.A. & Minella, J.P.G. (2012): Fatores relacionados à susceptibilidade da erosão em entressulcos sob condições de manejo e uso do solo. Revista Brasileira de Engenharia Agrícola e Ambiental, 16(2): 337-346.

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E. & Montanarella, L. (2015a): Estimating the soil erosion cover-management factor at the European scale. Land Use Policy, 48(1): 38-50.

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J. & Alewell, C. (2015b): Modelling the eff ect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environmental Science & Policy, 51(2): 23-34.

Potts, J. (2014): Coffee market. In: Ilnycky, R.; Holmes, D. & Rickert, E. (Ed.). The state of sustainability initiatives review 2014: standards and the green economy. Winnipeg: International Institute for Sustainable Development, p. 155-183.

Prochnow, D., Dechen, S.C.F., de Maria, I.C., Castro, O.M. & Vieira, S.R. (2005): Razão de perdas de terra e fator C da cultura do cafeeiro em cinco espaçamentos, em Pindorama (SP). Revista Brasileira de Ciência do Solo, 29(3): 91-98.

Santos, R.D., Lemos, R.C., Santos, H.G., Ker, J.C. & Anjos, L.H.C. (2005): Manual de descrição e coleta de solo no campo. 5th rev. e ampl. Viçosa: Sociedade Brasileira de Ciência do Solo. 100pp.

Sartori, A., Lombardi Neto, F. & Genovez, A.M. (2005): Classificação hidrológica de solos brasileiros para a estimativa da chuva excedente com o método do serviço de conservação do solo dos Estados Unidos. Parte 1: Classificação. Revista Brasileira de Recursos Hídricos, 10(2): 05-18.

SCS - Soil Conservation Service (1972): Hidrology Handbook. SCS National Engineering Handbook. Washington: US Department of Agriculture, 4(1): 47-75.

Silva, B.P.C., Silva, M.L.N., Batista, P.V.G., Pontes, L.M., Araújo, E.F. & Curi, N. (2016): Soil and water losses in eucalyptus plantation and natural forest and determination of the USLE factors at a pilot sub-basin in Rio Grande do Sul, Brazil. Ciência e Agrotecnologia, 40(2): 432-442.

Silva, M.L.N., Curi, N., Ferreira, M.M., Lima, J.M. & Ferreira, D.F.(1999): Proposição de modelos para estimativa da erodibilidade de Latossolos brasileiros. Pesquisa Agropecuária Brasileira, 34(1): 2287-2298.

Tavares, A.S., Spalevic, V., Avanzi, J.C., Nogueira, D.A., Silva, M.L.N. & Mincato, R.L. (2019): Modeling of water erosion by the erosion potential method in a pilot subbasin in Southernern Minas Gerais. Semina: Ciências Agrárias, 40(2): 555-572.

UFV - Universidade Federal de Viçosa, CETEC-T - Fundação Centro Tecnológico de Minas Gerais, UFLA - Universidade Federal de Lavras & FEAM - Fundação Estadual do Meio Ambiente. (2010): Mapa de Solos Do Estado de Minas Gerais: legenda expandida. Belo Horizonte: Fundação Estadual do Meio Ambiente. 53pp.

USGS - United States Geological Survey. Earth Explorer (2017). (also avaliable at: <http://earthexplorer.usgs.gov>).

Williams, J. R. (1975): Sediment-yield prediction with Universal Equation using runoff energy factor. In: Present and prospective technology for predicting sediment yield and sources. Oxford: USDA. ARS-S-40, 244-252.

Zhang, Y., Degroote, J., Wolter, C. & Sugumaran, R. (2009): Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS Framework to Assess Soil Erosion Risk. Land Degradation & Development, 20(4): 84-91.