Adaptation and application of the erosion potential method for tropical soils[1]

Adaptação e aplicação do método de erosão potencial para solos tropicais

Natanael Rodolfo Ribeiro Sakuno[2], Augusto Cesar Ferreira Guiçardi[2], Velibor Spalevic[3], Junior Cesar Avanzi[4], Marx Leandro Naves Silva[4] and Ronaldo Luiz Mincato[5]*

ABSTRACT - The water erosion process has a considerable negative effect on tropical soils, causes soil losses from arable land and reduces the capacity to support surrounding ecosystems. Estimating soil losses caused by water erosion is fundamental for evaluating the impacts of various production systems. Therefore, improving soil loss estimates via the adaptation of models for different edaphoclimatic environments is necessary for estimating local geographic and climatic differences. This study aimed to adapt, apply and evaluate the potentialities of the Potential Erosion Method for Latosols of the Hydrographic Subbasin of Caçús Stream, southern Minas Gerais State. Geological, topographic, pedological, climatic and land use and occupation data were processed via Geographic Information Systems and compared with those obtained by the Revised Universal Soil Loss Equation. The erosion intensity coefficient, Z, was 0.28, indicating weak erosion intensity, and the estimated average soil losses were 31 Mg ha^{-1} year^{-1} by the Potential Erosion Method and 36 Mg ha^{-1} year^{-1} by the Revised Universal Soil Loss Equation, which were both above the soil loss tolerance. The model results and comparisons indicated that the Potential Erosion Method has excellent performance and can be applied to estimate sediment production via water erosion in tropical soils.

Key words: Modeling of water erosion. RUSLE. Tropical soils.

RESUMO - A erosão hídrica é o processo que mais afeta negativamente os solos tropicais. Isso causa perdas de solos agricultáveis e reduz a capacidade de suporte aos ecossistemas. Estimativas das perdas de solo por erosão hídrica são fundamentais para avaliar os impactos dos diversos sistemas de produção adotados. Para tanto, melhorar as estimativas de perdas de solo por meio da adequação dos modelos para diferentes ambientes edafoclimáticos são necessárias para que as estimativas do modelo reflitam as diferenças geográficas e climáticas locais. Este estudo visou adaptar, aplicar e avaliar as potencialidades do Método de Erosão Potencial em Latossolos da Sub-bacia Hidrográfica do Ribeirão Caçús, Sul do Estado de Minas Gerais. Foram processados em Sistemas de Informação Geográfica dados geológicos, topográficos, pedológicos, climáticos e de uso e ocupação do solo. Os dados foram comparados aos obtidos pela Equação Universal de Perdas de Solo Revisada. O resultado do coeficiente de intensidade de erosão, Z, foi de 0,28, indicando ligeira intensidade de erosão. As perdas de solo médias estimadas foram de 31 Mg ha^{-1} ano^{-1} pelo Método de Erosão Potencial e 36 Mg ha^{-1} ano^{-1} pela Equação Universal de Perdas de Solo Revisada, ambas acima da tolerância de perdas de solo. A aplicação e comparação dos modelos supracitados, indicou que o Método de Erosão Potencial apresentou excelente desempenho, podendo ser aplicado para estimativas das taxas de produção de sedimentos por erosão hídrica em solos tropicais.

Palavras-chave: Modelagem da erosão hídrica. RUSLE. Solos tropicais.

INTRODUCTION

Water erosion is considered the primary cause of soil degradation, especially in tropical regions. The problem is enhanced by climate change, intensive land use, rainfall intensification, and runoff increases mainly in areas where conservationist management practices are neglected (LIMA *et al*., 2015). Dechen *et al*. (2015) estimated that the soil losses of temporary or annual crops in Brazil have reached 616.5 million Mg ha^{-1} year^{-1}, which is equivalent to a cost of US $1.3 billion.

Prediction models are essential for assessing environmental impacts, especially in the face of a growing world population and the associated increases in food, water, and energy consumption. Thus, studies on water erosion guide the adoption of mitigation measures and support soil and water conservation, as well as the restoration and repair of environmental impacts (SANTOS *et al*., 2017).

Soil loss estimates, however, should be compared to Soil Loss Tolerance (T) limits to determine whether they affect long-term agricultural sustainability. Conceptually, the T value corresponds to the soil formation rate. Therefore, sustainability is only possible if the losses are equal to the soil formation rate. However, obtaining the T boundary is still controversial due to the difficulties of accurately quantifying the factors and processes involved in soil formation.

In Brazil, the T calculation by Bertol and Almeida (2000) is the most frequently used method because it considers more attributes that reflect soil formation. Thus, T calculations complement the estimates of erosion rates and allow for the assessment of soil degradation stages. However, soil losses are cumulative, and even areas with losses below the T limit may require improved management practices (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 2015) to prevent a lack of sustainability over time.

A comparison with benchmark models allows for the evaluation of the effectiveness of new soil loss estimation methods. In this context, the Revised Universal Soil Loss Equation (RUSLE) (RENARD *et al*., 1997) is the most frequently applied for estimating the erosion of Brazilian soils (BARRETTO; BARROS; SPAROVEK, 2008; OLIVETTI *et al*., 2015).

The Erosion Potential Method (EPM) (GAVRILOVIC, 1988) is infrequently used in America and more commonly used in Europe, the Middle East and North Africa (KOUHPEIMA; HASHEMI; FEIZN, 2011; NIKOLIC *et al*., 2018; NYSSEN *et al*., 2014; SPALEVIC *et al*., 2013; VUJACIC *et al*., 2015). In Brazil, the EPM has only recently been implemented (SILVA; CELSO; SILVA,

2014; TAVARES *et al*., 2017) because it is inadequate for tropical edaphoclimatic conditions. Milanesi, Pilotti and Clerici (2014) adapted the EPM model for the Italian Alps region, which has a constant snow presence, and showed the good fit of the model after modifications and its reliable sediment production estimates.

This study aimed to adapt the EPM to estimate soil losses due to water erosion in tropical soils and apply the method in the Hydrographic Subbasin of Caçús Stream, which is located in the municipality of Alfenas, southern Minas Gerais State.

MATERIAL AND METHODS

The EPM estimates the average soil loss (m^3 km^{-2} year^{-1}) using variables and coefficients that represent soil physical characteristics as well as the land use and management, temperature, rainfall, slope, erosion resistance and erosion observed in the field at the subbasin scale. Each coefficient is obtained from the equations described in Table 1 (GAVRILOVIC, 1988).

The original parameters of the EPM, developed for the edaphoclimatic conditions of the Balkans, need to be adapted to tropical soils.

Adaptation of the method to tropical soils

The index Tables that simulate water erosion processes were adjusted for tropical soil conditions. For soil erosion resistance (Y), the EPM integrates water infiltration and percolation processes as well as structural resistance to particle breakdown. The Y value ranges from 0.20 to 2.00 and changes according to the soil type and its source material (SILVA; CELSO; SILVA, 2014) (Table 2). However, the same source material may generate different soils with distinct erosion resistance (RESENDE *et al*., 2019) due to edaphoclimatic conditions. Thus, in addition to the source material, the soil class and respective Y values are described in Table 2.

The coefficient of erosion (Z) (Table 3) represents the intensity of the erosive process at the subbasin scale considering the following parameters: average air temperature (°C year^{-1}), soil erosion resistance coefficient, soil use and management, soil erosion features observed in the field and mean slope (%).

Soil protection coefficient (X$_a$)

The soil protection coefficient (X$_a$) expresses the area that is less susceptible to erosion due to soil use and management. The X$_a$ value ranges from 0.05 for areas with dense vegetation to 1.0 for bare soils.

Table 1 - Equations and parameters used to estimate soil loss by the EPM

	Equation	Parameters
I	$W_{yr} = T \cdot H_{yr} \cdot \pi \cdot \sqrt[2]{Z^3} \cdot R_u$	G_{yr} = mean soil loss (m³ km⁻² year⁻¹) T = temperature coefficient (Dim(*)) H_{yr} = mean precipitation (mm year⁻¹) Z = erosion coefficient (Dim) Ru = sediment retention coefficient (Dim)
II	$T = \sqrt[2]{\dfrac{t_0}{10} + 0{,}1}$	t_0 = mean air temperature (°C year⁻¹) Y = soil resistance to water erosion (Dim) X_a = land use and management (Dim) φ = erosion observed in the field (Dim)
III	$Z = Y \cdot X_a \cdot (\varphi + \sqrt[2]{I_{sr}})$	I_{sr} = mean slope (%)
IV	$R_u = \dfrac{(O \cdot D)^{0,5}}{0{,}25 \cdot (Lv \cdot 10)}$	O = length of the subbasin (km) D = slope length (m) Lv = length of the main stream (km)
V	$Q_{max} = A \cdot S_1 \cdot S_2 \cdot w \cdot \sqrt[2]{2 \cdot g \cdot D \cdot F}$	Q_{max} = maximum flow rate (m³ s⁻¹) A = basin shape coefficient (Dim(*)) $2_g DF^{0,5}$ = rainfall kinetic energy (m³ km⁻² s⁻¹)
VI	$S_1 = 0{,}4 \cdot f_p + 0{,}7 \cdot f_{pp} + 1{,}0 \cdot f_0$	f_p = very permeable rocks (%) f_{pp} = medium permeable rocks (%) f_0 = poor permeable rocks (%) S_1 = permeability coefficient S_2 = cover vegetation coefficient
VII	$S_2 = 0{,}6 \cdot f_s + 0{,}8 \cdot f_t + 1{,}0 \cdot f_g$	f_s = dense vegetation cover (%) f_t = medium vegetation cover (%) f_g = low vegetation cover (%)
VIII	$w = h_b \cdot (15{,}0 - 22{,}0 \cdot h_b - 0{,}3 \cdot \sqrt[2]{L_v})$	w = water percolation (m) h_b = mean water level in heavy rainfall (mm)

Dim(*): Dimensionless. Source: Gavrilovic (1988)

Table 2 - Erosion resistance coefficient (Y) for the soils of the Brazilian Soil Classification System

Gavrilovic (1988)		Adaptation to tropical conditions		
Lithology and related soils	Y	Source rock	SiBCS[1] soils	Y
Rocky outcrops	0.25	Rocky outcrops	-	0.25
Well-structured alluvial soils	0.50	River sediments	RY, G, O, S	0.50
Vertisols and poorly drained soil	0.60	Basic and ultrabasic rocks, Amphibolites, Argylites, Shales	L, M	0.60
			P, N, F	0.70
Cambisols and shallow soils	0.80	Granites, Gneisses and Migmatites	L*, P*, S*, N, T	0.80
Carbonate, ferruginous and silicate soils associated with organic matter	0.90		CH, F*, T*	0.90

Rev. Ciênc. Agron., v. 51, n. 1, e20186545, 2020

3

Continued Table 2

Spodosols and degraded schist	1.00		
Soils derived from sedimentary rocks	1.10	Limestones, Marbles and Evaporites	E, V	1.20
Soils derived from karst relief	1.20		
Poorly aggregated soils	1.60		E, RR, C	1.50
Sand, gravel and loose soil	2.00	Limestones, Marbles and Evaporites	RL*, T*, C*	2.00

Notes: [1] Brazilian Soil Classification System; * Presence of quartz sand. RY: Fluvic Neosol; G: Gleysols; O: Organosols; S: Planosols; F: Plintosols; L: Oxisols; P: Argisols; N: Nitosols; M: Chernosols; CH: Humic Cambisol; C: Cambisols; T: Luvisols; E: Spodosols; V: Vertisols; RR: Regolithic Neossol; and RL: Litholic Neossol

Table 3 - Categories of erosion intensity, erosion coefficient (Z), and erosion coefficient mean values

Categories	Erosion intensity	Erosion Coefficient (Z)	Average of Z
I	Very severe	$Z > 1.0$	$Z = 1.25$
II	Severe	$0.71 < Z < 1.0$	$Z = 0.85$
III	Moderate	$0.41 < Z < 0.7$	$Z = 0.55$
IV	Weak	$0.20 < Z < 0.4$	$Z = 0.30$
V	Very weak	$Z < 0.19$	$Z = 0.10$

Source: Adapted from Gavrilovic (1988) and Yousefi *et al.* (2014)

Fanetti and Vezzoli (2007) suggested changing the categorization of the X_a based on different land use categories (Table 4), with urban areas considered potentially erosive and assigned a value higher than zero. These authors included urbanization variables as well as vegetation types.

Table 4 - Values of soil cover and management coefficients (X_a)

Land use classes	X_a
Disperse urbanization	0.05
Low urbanization	0.10
Discontinued urbanization	0.15
Continued urbanization	0.18
Dense urbanization	0.20
Native forest	0.40
Fields and pastures between forests	0.50
Pastures and fields	0.60

Source: Fanetti and Vezzoli (2007)

The EPM parameters visible erosion (φ), Y, and X_a were analyzed to determine the magnitude of the average soil losses. Small fluctuations in the values result in significant changes in soil loss estimates.

The potential and usual land uses in Brazil were considered to define the X_a coefficient (Table 5) as well as the parameter sensitivity. The assigned coefficient should consider the degree of crop development and not just the phenological stages. The EPM should consider the various stages of agricultural development when determining the average annual soil loss.

The most traditional temporary crops in tropical soils include rice, beans, corn, cassava, soybeans, and sugar cane, and the permanent crops currently include orange, banana, cocoa, coffee, and coconut. Permanent crops retain their canopy structure throughout the year and over a long period, thus offering higher protection to the soil when compared to temporary or annual crops.

Erosion Potential Method application

The EPM was applied to the hydrographic subbasin of Caçús Stream (Figure 1), which was previously studied by Olivetti *et al.* (2015). However, these authors used the RUSLE model to evaluate soil losses. The subbasin occupies an area of 2,080 ha, extends between 21°26' to 21°29' S and 45°56' to 46°00' W along the southern plateau of Minas Gerais and is part of the Rio Grande River Basin. The climate is Tropical Mesothermal (CwB) (SPAROVEK; VAN LIER; DOURADO NETO, 2007). The geological framework is formed by biotite and garnet biotite polydeformed Proterozoic gneisses in

4

Rev. Ciênc. Agron., v. 51, n. 1, e20186545, 2020

Table 5 - Possible methods of adapting to tropical uses with X_a coefficients

Gavrilovic (1988)	X_a	Authors	X_a
Bare soil	1.00	Bare soil	0.90 – 1.00
Tillage	0.90	Temporary or annual crops	0.80 – 0.90
		Temporary or annual crops with management	0.70 – 0.80
Orchard	0.70	Permanent crops	0.60 - 0.70
		Permanent crops with management	0.50 – 0.60
Pasture	0.60	Pasture	0.40 - 0.50
		Field	0.30 - 0.40
Field	0.40	Degraded forest	0.20 – 0.30
Degraded forest	0.60	Slightly degraded forest	0.05 – 0.20
Dense forest	0.05	Native forest	0.05

the physiographic unit called *mares de morros*, which is translated as "seas of hills" and was formed by the union of several wavy elevations.

Figure 1 - Location map of the hydrographic subbasin of Caçús Stream, Alfenas, MG
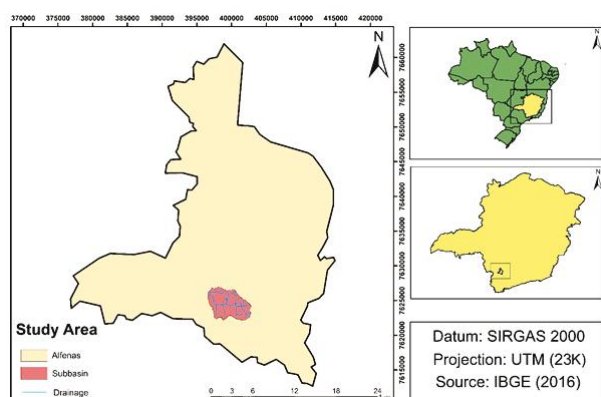
The geospatial characteristics of the subbasin were obtained from the topographic map of Alfenas (FOLHA SF 23-1-1-3) (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 1970) at a scale of 1:50.000 (digital format); a digital elevation model at a scale of 1:50.000, which was used to calculate the watershed area, line contour length, area of the largest and inferior parts of the river, natural length of the main watercourse and distance between the line contours; geological map at a scale of 1:100.000, which was used to classify the permeability (%) of the basin rocky substrate materials (i.e., very permeable, moderately permeable and slightly permeable) (UNIVERSIDADE FEDERAL

DO RIO DE JANEIRO; COMPANHIA DE PESQUISA DE RECURSOS MINERAIS, 2010); digital soil maps, which were based on the classes of declivity from Empresa Brasileira de Pesquisa Agropecuária (2006) and the map of soils of Minas Gerais at 1:650.000 from Universidade Federal de Viçosa *et al.* (2010) according to Mcbratney *et al.* (2003); and land use data (percentage), which were based on Landsat-8 satellite imagery from 2016 at orbit 219, point 75 and CBERS-4 imagery from 2016 at orbit 159 and point 123. Multispectral bands from the images were combined with the panchromatic band to increase the spatial resolution. Multispectral images from Landsat-8 and the panchromatic image from CBERS-4, with original resolutions of 30 m and 10 m, respectively, achieved resolutions of 15 m and 5 m. Weather data included the level of heavy rain in mm, maximum monthly precipitation, average annual air temperature in °C and average annual precipitation in mm. These values were calculated from the average annual heavy rainfall above 70 mm over 24 h for the period from 1981 - 2016 recorded at the Alfenas and Machado Rain Stations.

After data acquisition and processing, the DEM was elaborated based on the contour lines of the topographic map and generated altimetric points. Using the DEM and the relief classes from Embrapa (2006), a slope map of the area was generated and the average inclination (%) was determined. The Digital Surface Model (MDS) was obtained by combining the slope map and soil classess, according to McBratney, Mendonça Santos and Minasny (2003). In order to determine the average slope (I_{sr}), the length of the contour lines and area between them were taken under consideration, as well as the highest and lowest altitude, the equidistance between contour lines, and the highest and lowest altitude of the

contour lines, considering the variety of relief observed in the area.

The land use and management coefficient (X_a) was obtained adapting the coefficients of soil use and occupation from Gravilovic (1988). The soil losses estimates were performed using the software IntErO (Intensity of Erosion and Outflow) using the EPM algorithm (SPALEVIC *et al*., 2013).

To compare the results, the data were also calculated using GIS and EPM equation files, thus generating the spatial distribution of the soil losses.

RESULTS AND DISCUSSION

The IntErO input and output values from 2016 are summarized in Table 6.

The subbasin area (F) is 20.80 km², and it has a perimeter (O) of 24.96 km and minimum (H_{min}) and

maximum (H_{max}) altitude of 765 m and 960 m, respectively. The length of the main stream (L_v) is 7.09 km, and it has an average width of 10 m, and the shortest distance among upstream and downstream (L_m) is 5.95 km. The shape coefficient (A) is 0.69, which represents a subbasin with low flood propensity. The average annual rainfall is 1,500 mm, which may favor water erosion. The energetic potential of the water flow during abundant rainfall $(2gDF)^{1/2}$ was 168 m km⁻¹ s⁻¹, and the maximum flow rate in the river outflow (Q_{max}) was 69.83 m³ s⁻¹.

Regarding the permeability of the rocky substrate, 78% of the subbasin area was classified as medium permeability and 22% was classified as low permeability. The average slope of the subbasin (I_{sr}) was 13.22%, which indicates a wavy relief domain.

The large-scale difference in land use mappings was also sensitive in the land use and occupation mapping. Olivetti *et al*. (2015) used Landsat-5 imagery with a resolution of 30 m, whereas in this study, 5 m resolution imagery obtained by merging the bands in CBERS-4 or 15

Table 6 - Data input and output of the EPM using IntErO software

Data Input				Data Output (Results)			
Subbasin area	F	20.8	km²	Shape of the subbasin	A	0.69	Dim(*)
Perimeter	O	2.96	km	Development	m	0.44	Dim
Main river	L_v	7.09	km	Mean width	B	4.99	km
Shortest distance	L_m	5.95	km	(A) symmetry of the stream	a	0.13	Dim
Class I and II effluent	$\sum_L$	2.91	km	Drainage density	G	1.44	Dim
Mean width in parallel lines	L_b	4.17	km	Sinuosity of the stream	K	1.19	Dim
Largest area of the subbasin	F_v	11.09	km²	Mean altitude	H_{sr}	843	m
Smallest area of the subbasin	F_m	9.71	km²	Slope length	D	69.61	m
First contour level	h_0	770	m	Mean slope	I_{sr}	13.22	%
Minimum altitude	H_{min}	765	m	Height of the erosive base	H_{leb}	160	m
Maximum altitude	H_{max}	960	m	Erosion in the relief	E_r	23.91	Dim
Water level in heavy rainfall	h_b	82.5	mm	Permeability coefficient	S_1	0.77	Dim
Mean annual air temperature	t_o	22	°C	Vegetation cover coefficient	S_2	0.77	Dim
Mean annual rainfall	H_{yr}	1500	mm	Water percolation	W	1.02	m³
Medium permeability area	f_{pp}	0.78	Dim	Heavy rainfall	$(2gDF)^{1/2}$	168	m³ km⁻² s⁻¹
Area under good vegetation cover	f_s	0.3	Dim	Temperature	T	1.52	Dim
Area under agricultural cultivation	f_t	0.54	Dim	Maximum flow rate	Q_{max}	69.83	m³ s⁻¹
Area with no vegetation cover	f_g	0.16	Dim	Erosion (intensity)	Z	0.289	Dim
Soil resistance to erosion	Y	0.8	Dim	Total soil loss	W_{yr}	23,118	m³ year⁻¹
Land use and cover	X_a	0.47	Dim	Sediment retention	R_u	0.154	Dim
Erosion observed in the field	φ	0.41	Dim	Real soil loss	G	3,565	m³ year⁻¹
				Mean soil loss	G_{yr}	171	m³ km⁻² year⁻¹

Dim(*): Dimensionless

m resolution imagery from Landsat-8 were used, which achieved land use details with greater accuracy.

The permeability coefficient (S_1) of 0.77 indicated that impermeable areas were not identified, while the cover vegetation coefficient (S_2) of 0.77 indicated high soil protection (Table 4). The EPM estimated the total soil losses (W_{yr}) as 23,118 m³ year^{-1}, and the value calculated by GIS (Figure 2) was 19,488.86 m³ year^{-1} (Table 7). The difference between the EPM and GIS estimates was not significant.

The retention coefficient (R_u), which estimates the amount of sediment retained along the subbasin, was 0.154. The real soil loss (G_{yr}) was obtained by the total soil loss (W_{yr}) multiplied by the R_u. To compare the soil density results between the EPM and RUSLE, data in m³ km^{-2} year^{-1} were converted to Mg ha^{-1} year^{-1}, and the average density was 1.15 Mg m^{-3}.

The soil loss rate indicates the soil use and management under conservation practices and densified spacing. The X_a coefficient was 0.47, and the subbasin

Table 7 - Soil losses by the EPM and RUSLE

Use	Area (ha)	Wyr (m³ year^{-1})	Gyr (m³ year^{-1})	EPM (Mg ha^{-1} year^{-1})	RUSLE (Mg ha^{-1} year^{-1})	EPM Contribution (%)	RUSLE Contribution (%)
Coffee	204.11	2,899.90	446.58	3.97	1.72	12.66	4.73
Sugar cane	56.46	518.73	79.88	0.89	2.85	2.84	7.83
Bare soil	138.10	11,264.71	1.734.76	19.34	26.05	61.72	71.64
Corn	132.36	1,461.61	225.09	2.41	3.42	7.69	9.40
SIV	182.55	-	-	-	-		-
Native Forest	427.99	27.87	4.29	0.04	0.89	0.13	2.44
Pasture	939.43	3,316.04	510.67	4.69	1.43	14.96	3.96
Total	2,080.00	19,488.86	3,001.27	31.34	36.36	100	100

Figure 2 - Land use map (A), soil unit map (B), erosion intensity map (C), and soil loss map (EPM) (D) of the hydrographic subbasin of the Caçús Stream, Alfenas, MG
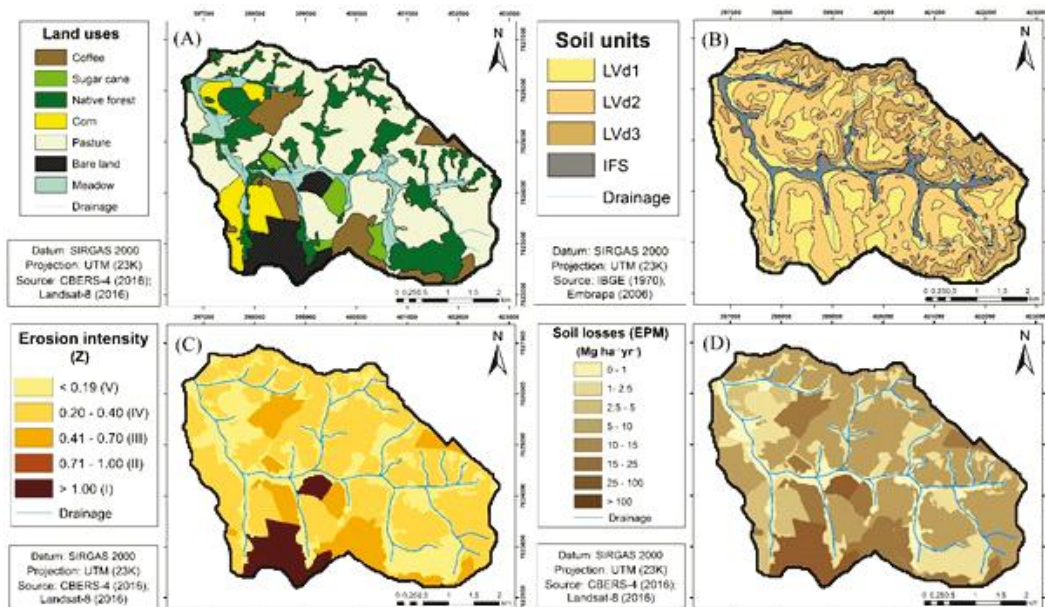
Notes: LVd1: Dystrophic Red Latosol in flat and smooth wavy reliefs; LVd2: wavy; LVd3: strong wavy; IFS: Indiscriminate Floodplain Soils

land use classes were 44% pastures, 30% native forests, 10% coffee, 6% corn, 7% bare soil and 3% sugar cane (Figure 2). Thus, the anthropogenic actions performed in the subbasin are not deleterious since the soils present high permeability, which indicates good soil structure preservation. In addition, the average slope of the area was not a hindering factor for land use and occupation.

The soil erodibility factor (K) of the RUSLE corresponds to the EPM soil resistance coefficient (Y). Indiscriminate Floodplain Soils (IFS) were not considered in the soil loss calculations since they are found in sediment deposition areas. To determine the Y coefficient, manual IFS polygonization was performed, and combined with the improved image spatial resolution, it generated more accurate soil loss spatial distributions (Figure 2).

Soil loss rates estimates by RUSLE and EPM are usually consistent and can identify areas adopt conservation measures. However, the soil losses estimated by the EPM are generally lower than that of the RUSLE except for with coffee and pasture. The difficulties in obtaining the C and P factors of the RUSLE from experimental plots can explain these results. Therefore, the estimates consider the soil physical characteristics and land use and management characteristics of other areas.

In the comparison between the soil losses by the EPM and RUSLE, the average was 31.34 Mg ha^{-1} year^{-1} for the EPM and 36.36 Mg ha^{-1}year^{-1} for the RUSLE, and the difference is due to the greater detail of the EPM parameters.

The EPM coefficient visible erosion (φ), which is not considered in the RUSLE, was 0.41 (Table 3), which corresponded to 44% of the subbasin under non-apparent erosion; 30% protected by native vegetation; 9% under moderate laminar erosion; 6% under severe laminar erosion; 2% under weak erosion; and 6% with agricultural areas under non-apparent erosion features.

Previous studies have discussed the use of the φ coefficient in soil loss calculations, and it is used in the erosion intensity coefficient (Z) calculation and results in high variation in the total soil losses estimated by the EPM (DRAGIČEVIĆ; KARLEUŠA; OŽANIĆ, 2017). The φ coefficient is not used in similar methods of sediment yield evaluations despite its arbitrary use increasing the modeling sensitivity (DRAGIČEVIĆ; KARLEUŠA; OŽANIĆ, 2016; KOUHPEIMA; HASHEMI; FEIZN, 2011). However, this parameter is not normally used in similar methods for sediment yield evaluations.

Native forest areas showed similar soil losses in both models because approximate values were assigned for natural factors. The bare soils presented the highest

estimates of soil losses, with rates above the T limit. However, lower rates were observed in the EPM, which considers the mean value of the coefficient of erosion observed in the field (φ). Corn cultivation also presented similar soil loss rates in both methods, although the results were below the T, which allows us to infer that crops with conservationist management do not damage the sustainability of agricultural soils.

The soil loss rates estimated by the EPM and RUSLE were 4.69 Mg ha^{-1} year^{-1} and 1.43 Mg ha^{-1} year^{-1} for pasture, respectively, and 3.97 Mg ha^{-1} year^{-1} and 1.72 Mg ha^{-1} year^{-1} for coffee, respectively. For pasture, lower C factor values were assigned in the RUSLE compared with the X_a coefficient values in the EPM. Even considering the high P factor values, the low C factor values reduced the estimates by the RUSLE. For sugar cane, the lower losses in the EPM were obtained due to the lower φ values compared to the P factor values of the RUSLE.

The Z coefficient of 0.28 reflects the abundance of erosive features observed on the ground and indicates that the subbasin belongs to the erosion intensity category IV or low. However, the erosion intensity was pronounced in intensive use areas, which has X_a values close to 1.0, which is considered bare soil.

The EPM and RUSLE showed equivalent soil losses when considering land use and land management. Both methods consider different coefficients and parameters that represent factors related to soil cover. A list of land use and management coefficients used to determine the loss spatialization is presented in Table 8.

An indirect relationship is observed between the conservation practice parameters (P) from the RUSLE and erosive features observed in the field (φ) from the EPM. However, the values of these parameters used in the soil loss calculations have been tabulated. In the case of the C factor, the values were obtained from Olivetti *et al*. (2015). However, several authors disregard these parameters (BAHADUR, 2009).

The X_a of the EPM corresponds to the C factor of the RUSLE, although a similar comparison to φ cannot be made. However, a relationship is observed between P and φ because P represents conservationist practices, which reflect a higher or lower propensity for erosion, and φ also represents the area susceptible to erosion. Therefore, for pasture, sugar cane, and bare soil, the maximum value of P (1.00) was assigned (OLIVETTI *et al*., 2015), which increases the soil losses in these areas.

The EPM is characterized by a high degree of security in the calculation of sediment production, transport, and accumulation. The method can quickly and effectively estimate the potential erosion rates

Table 8 - Land use coefficient values assigned for the RUSLE and EPM

Land use	RUSLE		EPM	
	C	P	X_a	φ
Coffee	0.09	0.50	0.60	0.50
Sugar cane	0.10	1.00	0.80	0.30
Bare soil	1.00	1.00	1.00	1.00
Corn	0.12	0.01	0.70	0.15
Native forest	0.02	0.01	0.05	0.01
Pasture	0.08	1.00	0.50	0.50

*C: Land use cover management; P: conservation Practice; Xa: land use cover; and φ: erosion observed in the field

and sediment production at the river basin scale. The accuracy of the estimates obtained by the models is directly related to the researcher's knowledge in setting the factors and parameters used in the model calculations (BAHADUR, 2009; DRAGIČEVIĆ; KARLEUŠA; OŽANIĆ, 2017; NYSSEN *et al.*, 2014).

Gavrilovic's method is advantageous because is a fast and effective method of estimating soil losses by water erosion. In addition, the EPM can be applied even when physical and edaphoclimatic data are lacking and in areas without previous soil erosion research.

Amorim *et al.* (2010) evaluated the soil loss estimates by several methods and concluded that the errors associated with the estimates are higher for the lowest loss rates and smaller for the highest loss rates. Moreover, studies have also indicated that areas with losses below the TPS may require constant management improvements to reduce soil losses and promote agricultural and environmental sustainability as recommended by Food and Agriculture Organization of the United Nations (2015).

When applying the EPM, the model sensitivity must be considered by assessing the responses caused by changes in each parameter and their contributions to the results. Accordingly, because the parameters are adjusted to the model, the EPM is an effective tool for performing socioeconomic and environmental planning and proposing conservationist land use and occupation policies in tropical regions.

CONCLUSIONS

1. The Erosion Potential Method is effective, and because it is a conceptual model, it is less expensive and can be used in subbasins with limited available data;

2. Although the Erosion Potential Method was not validated by geostatistical models, experimental plot data or sedimentological data, its application, which was performed simultaneously with the Revised Universal Soil Loss Equation, showed that the model was able to point out areas with soil losses above the soil loss tolerance limits in tropical regions;

3. Estimations of soil loss and erosion intensity by the EPM contributes to risk assessments of the degradation of tropical and subtropical soils and represents a tool for assessing the socioeconomic sustainability of agricultural activities.

ACKNOWLEDGMENTS

REFERENCES

AMORIM, R. S. S. *et al.* Avaliação do desempenho dos modelos de predição da erosão hídrica USLE, RUSLE e WEPP para diferentes condições edafoclimáticas do Brasil. **Engenharia Agrícola**, v. 30, n. 6, p. 1046-1049, 2010.

BAHADUR, K. C. K. Mapping soil erosion susceptibility using remote sensing and GIS: a case of the Upper Name Wa Watershed. **Environmental Geology**, v. 55, n. 1, p. 695-705, 2009.

BARRETTO, A. G. O. P.; BARROS, M. G. E.; SPAROVEK, G. Bibliometria, história e geografia da pesquisa brasileira em

erosão acelerada do Solo. **Revista Brasileira de Ciência do Solo**, v. 32, n. 6, p. 2443-2460, 2008.

BERTOL, I.; ALMEIDA, J. A. Tolerância de perda de solo por erosão para os principais solos do Estado de Santa Catarina. **Revista Brasileira de Ciência do Solo**, v. 24, n. 3, p. 657-668, 2000.

DECHEN, S. C. F. *et al.* Perdas e custos associados à erosão hídrica em função de taxas de cobertura do solo. **Bragantia**, v. 74, n. 2, p. 224-233, 2015.

DRAGIČEVIĆ, N.; KARLEUŠA, B.; OŽANIĆ, N. A review of the Gavrilović method (Erosion Potential Method) application. **Gradevinar**, v. 9, n. 68, p. 715-725, 2016.

DRAGIČEVIĆ, N.; KARLEUŠA, B.; OŽANIĆ, N. Erosion Potential Method (Gavrilović method) sensitivity analysis. **Soil and Water Research**, v. 12, n. 1, p. 51-59, 2017.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. Centro Nacional de Pesquisa de Solos. **Sistema brasileiro de classificação de solos**. 2. ed. Rio de Janeiro: Embrapa Solos, 2006.

FANETTI, D.; VEZZOLI, L. Sediment input and evolution of lacustrine deltas: the Breggia and Greggio rivers case study (lake Como, Italy). **Quaternary International**, v. 173/174, p. 113-124, 2007.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. Intergovernmental Technical Panel on Soils. **Status of world's soil resources**. FAO-ITPS-GSP Main Report, p. 125-127, 2015.

GAVRILOVIC, Z. Use of an empirical method (Erosion Potential Method) for calculating sediment production and transportation in unstudied or torrential streams. *In:* INTERNATIONAL CONFERENCE ON RIVER REGIME HYDRAULICS RESEARCH LIMITED, p. 411-422, 1988.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Carta topográfica do município de Alfenas (FOLHA SF 23-1-1-3)**. Escala 1:50000. Rio de Janeiro: IBGE, 1970.

KOUHPEIMA, A.; HASHEMI, S. A. A.; FEIZN, S. A study on the efficiency of Erosion Potential Model (EPM) using reservoir sediments. **Elixir International Journal**, n. 38, p. 4135-4139, 2011.

LIMA, C. A. *et al*. Práticas agrícolas no cultivo da mandioca e suas relações com o escoamento superficial, perdas de solo e água. **Revista Ciência Agronômica**, v. 46, n. 4, p. 697-706, 2015.

MCBRATNEY, A. B.; MENDONÇA SANTOS, M. L.; MINASNY, B. On digital soil mapping. **Geoderma**, v. 117, n. 1, p. 3-52, 2003.

MILANESI, L.; PILOTTI, M.; CLERICI, A. The application of the Erosion Potential Method to Alpine areas: methodological improvements and test case. *In*: Lollino, G. *et al*. (ed.). **Engineering geology for society and territory**: river basins, reservoir sedimentation and water resources. 2014. v. 3. p. 347-350.

NIKOLIC, G. *et al.* Variability of soil erosion intensity due to vegetation cover changes: case study of Orahovacka Rijeka, Montenegro. **Notulae Botanicae Horti Agrobotanici**, v. 47, n. 1, p. 237-248, 2018.

NYSSEN, J. *et al.* Twentieth century land resilience in Montenegro and consequent hydrological response. **Land Degradation and Development**, v. 35, n. 4, p. 336-349, 2014.

OLIVETTI, D. *et al.* Spatial and temporal modeling of water erosion in dystrophic red latosol (Oxisol) used for farming and cattle raising activities in a subbasin in the South of Minas Gerais. **Ciência e Agrotecnologia**, v. 39, n. 1, p. 58-67, 2015.

RENARD, K. G. *et al.* Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture. **Agriculture Handbook**, v. 703, 1997.

RESENDE, M. *et al.* **Da rocha ao solo**: enfoque ambiental. Lavras: UFLA, 2019. 513 p.

SANTOS, J. C. N. *et al.* Sediment delivery ratio in a small semi-arid watershed under conditions of low connectivity. **Revista Ciência Agronômica**, v. 48, n. 1, p. 49-58, 2017.

SILVA, R. M.; CELSO, A. G. S.; SILVA, A. M. Predicting soil erosion and sediment yield in the Tapacurá Catchment, Brazil. **Journal of Urban and Environmental Engineering**, v. 8, n. 1, p. 75-82, 2014.

SPALEVIC, V. *et al.* Prediction of the soil erosion intensity from the river basin Navotinski, Polimlje (northeast Montenegro). **Agriculture and Forestry**, v. 59, n. 2, p. 9-20, 2013.

SPAROVEK, G.; VAN LIER, Q. J.; DOURADO NETO, D. Computer assisted Köppen climate classification: a case study for Brazil. **International Journal of Climatology**, v. 27, p. 257-266, 2007.

TAVARES, A. S. *et al.* Modelos de erosão hídrica e tolerância das perdas de solo em Latossolos distróficos no sul de Minas Gerais. **Revista do Departamento de Geografia**, p. 268-277, 2017. Volume especial – Eixo 12.

UNIVERSIDADE FEDERAL DE VIÇOSA *et al.* **Mapa de solos do Estado de Minas Gerais**. Escala 1:650:000. Belo Horizonte: Fundação Estadual do Meio Ambiente, 2010. 49 p.

UNIVERSIDADE FEDERAL DO RIO DE JANEIRO; COMPANHIA DE PESQUISA DE RECURSOS MINERAIS (BRASIL). **Mapa Geológico da Folha Alfenas (SF-23-V-D-II)**. Escala 1:100.000. Rio de Janeiro, 2010.

VUJACIC, D. *et al.* Calculation of runoff and sediment yield in the Pisevska Rijeka watershed, Polimlje, Montenegro. **Agriculture e Forestry**, v. 61, n. 2, p. 225-234, 2015.

YOUSEFI, S. *et al*. An estimation of sediment by using erosion potential method and geographic information systems in Chamgardalan watershed: a case study of Ilam province, Iran. **Geodynamics Research International Bulletin - GRIB**, v. 2, n. 2, p. 1-5, 2014.