



Water erosion modeling by the Erosion Potential Method and the Revised Universal Soil Loss Equation: a comparative analysis

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ABSTRACT

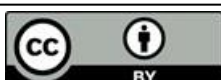
Water erosion is the principal degradation process of tropical soils, and its effects can be measured by modeling techniques. Erosion models provide a diagnosis of the soil loss intensity and can support the planning of soil conservation practices. Models with low data requirements, such as the Revised Universal Soil Loss Equation (RUSLE) and, more recently, the Erosion Potential Method (EPM), are mainly applied in Brazil. Thus, the objective of this work was to estimate water erosion soil-loss rates using the EPM and RUSLE models on a tropical subbasin, followed by a comparison of their outcomes. The models' application considered soil physical parameters, edaphoclimatic conditions of the area, land use, and subbasin management practices. The accuracy of the methods was verified using total transported sediment and water discharge data. We compared the models using Pearson's correlation analyses, considering a 5% of significance. We found a predominance of moderate-intensity erosion with average soil loss of 1.17 and 1.46 Mg ha⁻¹ year⁻¹, measured by EPM and RUSLE, respectively. The EPM model underestimated soil losses by 15.27%, and RUSLE overestimated by 19.08%, indicating a higher percentage of areas with high erosion rates (4.60%). The models presented results with a different order of magnitude, but with significant correlations, indicating that both methods pointed out similar zones of intense and light-erosion rates.

Keywords: RUSLE, Soil Conservation, Soil Losses.

Modelagem da erosão hídrica pelo Método de Erosão Potencial e pela Equação Universal de Perda de Solo Revisada: uma análise comparativa

RESUMO

A erosão hídrica é o principal processo de degradação dos solos tropicais e seus efeitos podem ser mensurados por técnicas de modelagem. A modelagem fornece um diagnóstico sobre as taxas erosivas e é capaz de auxiliar no planejamento de práticas de conservação do solo. No Brasil, são aplicados principalmente modelos com baixa exigência de dados, como a



Equação Universal de Perda de Solo Revisada (RUSLE) e, mais recentemente, o Método de Erosão Potencial (EPM). Desta forma, o objetivo do trabalho foi estimar as perdas de solo por erosão hídrica em uma sub-bacia hidrográfica tropical, localizada no sudeste brasileiro, utilizando o EPM e a RUSLE e comparar os seus resultados. A aplicação dos modelos considerou as características físicas, edafoclimáticas, o uso de solo e as práticas de manejo da sub-bacia. A precisão dos métodos foi verificada usando dados de sedimentos totais transportados e de descarga de água e realizou-se a análise de correlação entre os resultados, utilizando o coeficiente de correlação de Pearson, com 5% de significância. Na sub-bacia ocorreu predomínio de erosão em intensidade moderada com perda de solo média de 1,17 e 1,46 Mg ha⁻¹ ano⁻¹, mensuradas pelo EPM e RUSLE, respectivamente. O modelo EPM subestimou as perdas de solo em 15,27% e a RUSLE superestimou em 19,08%, apontando maior porcentagem de áreas com elevadas taxas erosivas (4,60%). Os modelos apresentaram resultados com ordem de grandeza distintas, porém com correlação significativa indicando que ambos os métodos apontam maiores e menores taxas erosivas, nas mesmas áreas da sub-bacia.

Palavras-chave: Conservação do Solo, Perdas de Solo, RUSLE.

1. INTRODUCTION

Water erosion is the major degradation process on tropical soils that can cause several negative impacts and compromise the sustainability of agricultural production. The total of soil losses by water erosion in Brazil is currently estimated in about 850 million Mg year⁻¹ (Merten and Minella, 2013), generating local impacts by the damages in plantations that cause soil-nutrient removal, as well as external effects like siltation and water-body pollution (Posthumus *et al.*, 2015).

Conventional methods that involve field experiments to determine erosion rates and identify susceptible zones are expensive and require a high demand for time. Also, it can be impracticable to implement these procedures on a hydrographic basin-scale (Ganasri and Ramesh, 2016; Efthimiou *et al.*, 2017). Therefore, the use of modeling techniques can help to overcome these limitations and to obtain precise and effective results.

Erosion models are easy to interpret, require minimal resources, and can be executed with available information. These models, when combined with Geographic Information Systems (GIS), allow the spatialization of results and identify high erosion risks, contributing to the planning of mitigation measures (Ganasri and Ramesh, 2016).

Brazil lacks data availability, especially regarding soil maps that are scarce or unavailable, and climate due to the non-spatialized information and several blanks on the hydrometeorological station's database. There are other problems concerning the data acquisition, once the information is scattered between different agencies, which lead to the selection of models that comply with low data demand criteria and can provide a satisfactory diagnosis.

The Revised Universal Soil Loss Equation (RUSLE), developed by Renard *et al.* (1997), is the most widespread method to evaluate erosion processes (Ganasri and Ramesh, 2016), and the Erosion Potential Method (EPM), created by Gavrilovic (1962), stands out for its ease of application, which led it to be used in studies involving tropical Brazilian soils (Tavares *et al.*, 2019; Sakuno *et al.*, 2020). However, few studies have compared the efficiency of the two models or the precision of their results (Amorim *et al.*, 2010).

Since the precise assessment of erosion is an essential element to design and implement targeted and effective soil conservation measures, our goal was to estimate soil loss rates by water erosion using the EPM and RUSLE models on a tropical subbasin, followed by a comparison of their outcomes. We tested the hypothesis that both models present a similar

spatial distribution of soil loss, pointing to similar zones of intense and light-erosion rates.

2. MATERIAL AND METHODS

2.1. Experimental Site

The study was performed in the José Lúcio Creek Subbasin (Figure 1), which belongs to the Rio Grande Basin, located in Conceição do Rio Verde, Minas Gerais, Brazil (from 479251 to 483469 meters W, and from 7574201 to 7570015 meters S, Zone 23K, Datum SIRGAS 2000 UTM).

The climate in this area, according to the Köppen classification, is subtropical highland (Cwb), characterized by humid hot summers, and dry, tempered winters, with an average annual temperature of 20°C and precipitation of 1,500 mm (Alvares *et al.*, 2013). The study field is in the Mantiqueira Mountains, the altitude ranges between 893 and 1,339 m (Figure 1A) and the relief is predominantly undulating, with an average inclination of 19.6% (Figure 1B).

We extracted the Digital Elevation Model (DEM) from the level curves of Minas Gerais, obtained in the Infraestrutura de Dados Espaciais do Sistema Estadual de Meio Ambiente e Recursos Hídricos (SISEMA, 2019) and with this model we elaborated a Declivity Map using the Slope tool from ArcMap 10.3 (ESRI, 2015). Using the digital Soil Map of Minas Gerais (UFV *et al.*, 2010) and field observations, we elaborated the digital map of soils of the area (Figure 1C), which showed that dystrophic Red Latosol and dystrophic Tb Haplic Cambisol are predominant, with 89.5% and 10.5%, respectively.

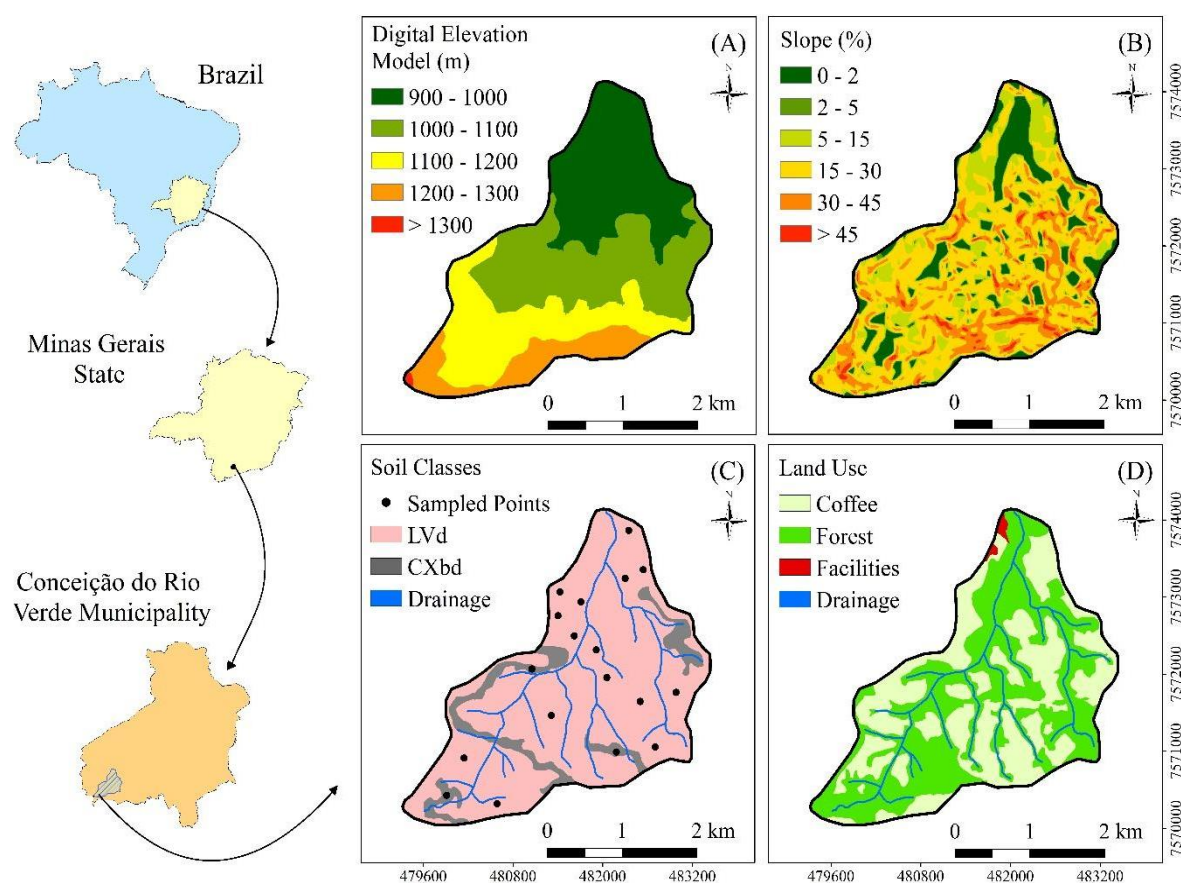


Figure 1. Location map, digital elevation model (A), slope map (B), digital soil map with soil collection sites (C) and land use map (D) of José Lúcio Creek Subbasin, Conceição do Rio Verde, south of Minas Gerais, Brazil. Notes: dystrophic Red Latosol (LVd) and dystrophic Tb Haplic Cambisol (CXbd).

The subbasin is occupied with coffee cultivation (46.2%), native and regenerating forest (48.7%), facilities (0.6%) and drainage net (4.5%) (Figure 1D). The Land Use Map was elaborated using a history of occupation of the Rio Verde Farm (Ipanema Agricultural SA) and satellite images from Landsat 8 Operational Land Imager (OLI), on bands 2, 3 and 4, orbit/point 219/75, obtained from Divisão de Geração de Imagens (INPE, 2019), which processing was also done using ArcMap 10.3 (ESRI, 2015).

2.2. Erosion Potential Method (EPM)

Erosion Potential Method (EPM) is an empirical model to estimate water erosion in hydrographic basins, taking into account parameters related to the climate, topography, soil type, and land use. The model has been widely applied worldwide and has recently been adapted to Brazilian edaphoclimatic conditions (Efthimiou *et al.*, 2017; Sakuno *et al.*, 2020).

The intensity of the erosion process (Z) (Gavrilovic, 1962) can be calculated by Equation 1:

$$Z = Y \cdot X_a \cdot (\varphi + \sqrt[2]{I_{sr}}) \quad (1)$$

Where, Y = soil resistance to water erosion, range from 2 to 0.25; X_a = land use and management coefficient, range from 1.0 to 0.05; φ = coefficient of visible erosion features, range from 1.0 to 0.1; and I_{sr} = average inclination of the area in percentage (%).

The Y value from the LVD and CXbd was 0.8 e 0.9, respectively. Latosols are the main soil in the area, which indicates that the subbasin presents high resistance to erosion. The X_a coefficient of 0.33 demonstrated that the subbasin presents high vegetal density and good soil cover. The φ value of 0.28 indicates the predominance of surface erosion. The parameters Y , X_a , and φ were determined based on tabulated values, established by Gavrilovic (1962) and adapted to the Brazilian edaphoclimatic conditions by Sakuno *et al.* (2020). The relief of the area is mostly undulating, with an average slope (I_{sr}) of 19.60%. The I_{sr} was determined using the Declivity Map (Figure 1B).

Zones with Z values higher than 1.0 are the ones with severe erosion, while areas with Z values lower than 0.19 represent those with less intense degradation (Gavrilovic, 1962). Using the Z coefficient, the real soil loss (W_{yr}) can be estimated in $Mg\ ha^{-1}\ year^{-1}$, as shown in Equation 2:

$$W_{yr} = \left(\sqrt[2]{\frac{t_0}{10}} + 0.1 \right) \cdot H_{yr} \cdot \pi \cdot \sqrt[2]{Z^3} \cdot Ds \quad (2)$$

Where, t_0 = average temperature in $^{\circ}C\ year^{-1}$; H_{yr} = average annual precipitation, in mm; Ds = soil average density in $kg\ dm^{-3}$.

The area presents a mean temperature of $20^{\circ}C$ (t_0) and a mean annual rainfall of 1,500 mm (H_{yr}). We obtained climate factors (H_{yr} and t_0) using data from a rainfall station, operated by the Instituto Nacional de Meteorologia (INMET, 2019), and located near the study area. The Ds of the area was determined through analysis of undisturbed soil samples (Blake and Hartge 1986), collected all over the subbasin, and presented a mean value of $1.24\ kg\ dm^{-3}$ (Figure 1C). Next, its values were incorporated into the equation to convert the unit $m^3\ year^{-1}$ to $Mg\ year^{-1}$ so the results could be expressed in the same unit as RUSLE, making the comparison doable.

Most predictive water erosion models do not consider the delivery, deposition, or transportation of sediments into the water bodies, and EPM innovates in this issue, because it has in its structure the retention coefficient (R_u) which is a way to determine the fraction of sediments retained in the subbasin, thus how much sediment is carried into the watercourses, representing the real soil loss. Therefore, the R_u coefficient was calculated according to Zempljic (1971), using Equation 3.

$$R_u = \frac{(O \cdot D)^{0.5} \cdot (L + Li)}{F \cdot (L + 10)} \quad (3)$$

Where, F = sub basin total area (8.60 km²); O = perimeter (13.50 km); D = average difference of elevation (0.17 km), obtained by the difference between the average altitude (1,066 m) and the minimum altitude (900 m); L = main watercourse length (5.20 km); and Li = secondary length (3.48 km).

2.3. Revised Universal Soil Loss Equation (RUSLE)

RUSLE (Equation 4) is an empirical equation to estimate water erosion that considers six individual and linearly related parameters (Equation 4). RUSLE is used worldwide due to its high degree of flexibility, allowing the model to be adapted to different regions with different edaphoclimatic conditions. In addition, there is extensive scientific literature that allows comparability of model results (Alewell *et al.*, 2019).

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (4)$$

Where, A = average annual soil loss, in Mg ha⁻¹ year⁻¹; R = rainfall erosivity factor, in MJ mm ha⁻¹ h⁻¹ year⁻¹; K = soil erodibility factor, in Mg ha⁻¹ MJ⁻¹ mm⁻¹; LS = topographic factor, given by the relationship between length (L) and inclination of the relief (S), dimensionless; C = cover and management factor, dimensionless; and P = conservation practices factor, dimensionless.

Using the erosivity map of Minas Gerais from Aquino *et al.* (2012), we determined the R-factor of the subbasin as 6,800 MJ mm ha⁻¹ h⁻¹ year⁻¹, while for the K-factor, that represents different susceptibility of soils to erosion, we adopted values that ranged from 0.026 to 0.035 Mg ha⁻¹ MJ⁻¹ mm⁻¹ for dystrophic Red Latosol (LVd) and dystrophic Tb Haplic Cambisol (CXbd), respectively (Silva *et al.*, 2009; Tavares *et al.*, 2019).

To determine the LS-factor, we used the Digital Elevation Model (DEM) and the Raster Calculator tool from ArcGIS 10.3, following Equation 5, established by Moore and Burch (1986). The final values ranged from 0 to 188, according to the topography, with an average of 5.6.

$$LS = \left(\frac{FA \cdot 10}{22.13} \right)^{0.4} \cdot \left(\frac{\sin(S)}{0.0896} \right)^{1.3} \quad (5)$$

Where, LS = topographic factor, dimensionless; FA = flow accumulation that is expressed as the cell numbers of the DEM grid; S = subbasin declivity (degrees); and 10 = DEM spatial resolution (m).

The C-factor varies, according to the vegetation cover, from 0 to 1, where higher values represent a higher soil degradation due to the impact of rainfall and to the surface runoff (Beskow *et al.*, 2009). This factor was established based on the literature, being 0.0866 for coffee cultivation zones (Prochnow *et al.*, 2005) and 0.015 for forests (Silva *et al.*, 2016).

The P-factor also varies between 0 and 1 and expresses the potential that management practices have to reduce soil erosion, where lower values indicate efficient conservation practices (Beskow *et al.*, 2009). Coffee cultivation zones in the study area obtained 0.5, and forests, 0.01.

The RUSLE estimates total sediments eroded from the subbasin and, to calculate the delivery rate, its outcome was multiplied by R_u coefficient. Lastly, the spatial distribution of the soil loss estimates obtained with both RUSLE and EPM were done using the Raster Calculator Tool, from ArcGIS 10.3 (ESRI, 2016), generating the soil-loss maps.

We performed a Pearson correlation test between the results of both methods, with a significance of 5%, relating five thousand points representing image pixels. These points were

randomly extracted from the soil losses maps of RUSLE and EPM with a 10 meters minimum distance of each other. Thereunto, we used the Create Random Points and Extract Value to Point tools from ArcGIS 10.3 (ESRI, 2016).

2.4. Models Validation

The validation of the models was done using the observed sediment calculation, which can be executed with data of the total of sediments transported in the water discharge (observed sediment), as proposed by Beskow *et al.* (2009).

Initially, we developed a discharge curve relating precisely the total of transported sediments with the water discharge (Figure 2), with data (total solids in water, and flow) from 1997 to 2010 (there was no data collected since then), obtained through an Measurement Station located near the estuary of the José Lúcio Creek (477209 m W and 7592560 m S), operated by the Instituto Mineiro de Gerenciamento de Recursos Hídricos (IGAM).

Then, after calculating the annual Observed SD using the discharge curve and information about the daily runoff obtained from the Agência Nacional de Águas (ANA, 2019), the outcome of transported sediment was compared to the soil loss estimates provided by RUSLE and EPM modeling.

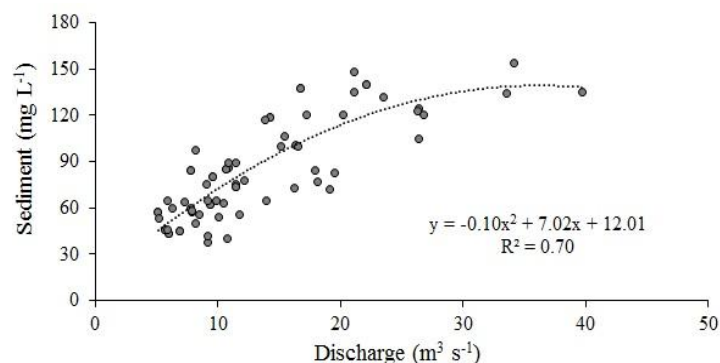


Figure 2. Water discharge curve (total solids in water x flow) on the José Lúcio Creek Subbasin, Conceição do Rio Verde, southern Minas Gerais, Brazil.

3. RESULTS AND DISCUSSION

Ribeirão José Lucio Sub-basin is predominantly covered by high-density coffee cultivation and woodland. The good vegetative coverage is reflected in the low value of the Z coefficient, which was 0.23, indicating that in the subbasin areas with low susceptibility to erosion predominate. Both RUSLE and EPM soil loss estimates are highly influenced by vegetative cover, and this is the main factor of anthropic interference in the erosion process (Renard *et al.*, 1997).

The EPM estimated total soil losses in the subbasin at 10,125.56 Mg year⁻¹, while the RUSLE result was 30% higher (13,449.01 Mg year⁻¹). The result is similar to that of Efthimiou *et al.* (2016), who compared the application of the RUSLE and EPM models in Greece, observed an estimate of the soil loss carried out by RUSLE about 10% higher than the results of the EPM.

The retention coefficient (R_u) of the sub-basin was calculated at 0.995, indicating that 9.95% of the sediments generated in the area reach watercourses (real soil loss), contributing to the silting up and the depreciation of water quality (Bispo *et al.*, 2017).

Based on R_u , EPM and RUSLE estimated the real soil loss at 1,007.49 and 1,343.15 Mg year⁻¹, with average losses of 1.17 and 1.56 Mg ha⁻¹ year⁻¹, respectively. Comparing the results

of soil losses with the observed sediment value of $1.31 \text{ Mg ha}^{-1} \text{ year}^{-1}$, we found that EPM underestimated the results by 15.27%, while RUSLE overestimated by 19.08%. Soil loss measured by EPM was closer to observed sediment. However, both methods exhibited satisfactory accuracy, and Pandey *et al.* (2007) supports the premise that errors below 20% allow the validation of soil-erosion model results. Thus, the results of the models are efficient for assessing the current state of soil degradation in the subbasin, as well as for planning measures to reduce water erosion.

The maps of soil losses generated by EPM and RUSLE are shown in Figure 3, pointing to lower erosion rates in the forest areas.

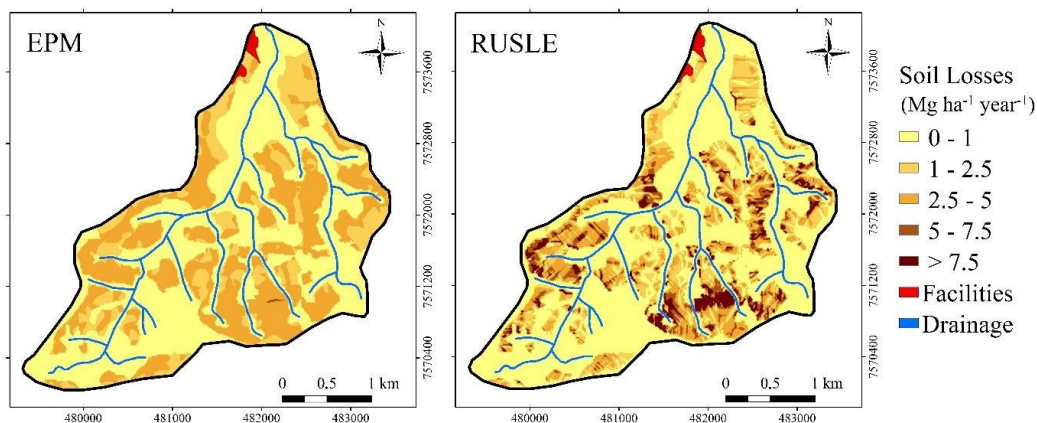


Figure 3. Spatial distribution of the soil loss estimates of Potential Erosion Method (EPM) and Revised Universal Soil Loss Equation (RUSLE) in the José Lúcio Creek Subbasin, Conceição do Rio Verde, southern of Minas Gerais, Brazil.

The range of the variation in soil losses for the subbasin was higher for RUSLE (ranging from 0 and $101 \text{ Mg ha}^{-1} \text{ year}^{-1}$), while EPM estimated the losses between 0 and $5.6 \text{ Mg ha}^{-1} \text{ year}^{-1}$. Despite this disparity, the results of both models presented a significant correlation ($p < 0.001$) (Figure 4), indicating that even with different orders of magnitude, the two models pointed to similar zones of intense- and light-erosion, which is notable on Figure 3.

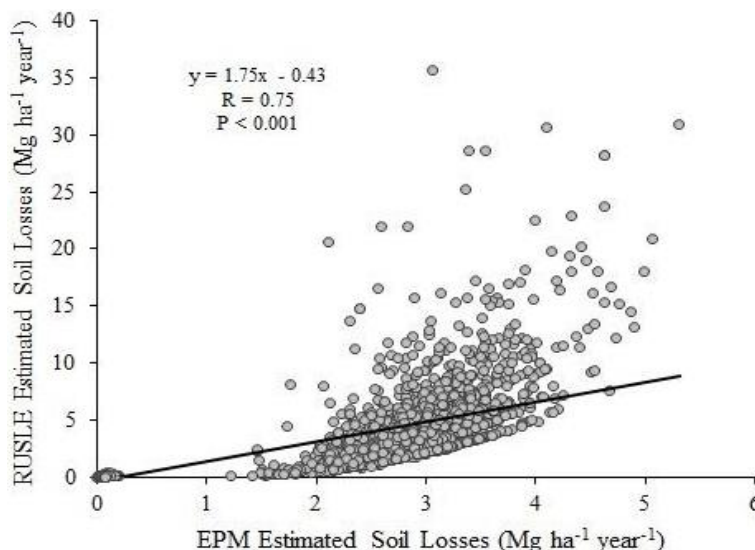


Figure 4. Linear correlation between estimates of soil losses generated by the Potential Erosion Method (EPM) and the Revised Soil Loss Equation (RUSLE) in the José Lúcio Creek Subbasin, Conceição do Rio Verde, southern Minas Gerais, Brazil.

Following the proposal of Avanzi *et al.* (2013) and Beskow *et al.* (2009), we classified the erosion rates qualitatively to determine the intensity of the process. Both models showed a predominance of very weak erosion, which can be explained by the adoption of conservation practices on the coffee crops, and also by the presence of areas with dense vegetative cover. RUSLE found a higher percentage of areas with severe degradation process (4.6%), while EPM detected only 0.07% of the subbasin with moderate erosion, with no occurrence of severe soil losses (Table 1).

Table 1. Soil loss classes estimated by Erosion Potential Method and by Revised Universal Soil Loss Equation for the José Lúcio Creek hydrographic subbasin, Conceição do Rio Verde, southern Minas Gerais, Brazil.

Soil Loss (Mg ha ⁻¹ year ⁻¹)	Area (%)		Soil Loss Classes*
	EPM	RUSLE	
0 – 1	53.86	66.54	Very weak
1 - 2.5	15.70	10.58	Weak
2.5 – 5	30.41	12.80	Weak to Moderate
5 - 7.5	0.07	5.48	Moderate
> 7.5	0.00	4.60	Severe

*Soil loss classes adapted from Beskow *et al.* (2009) and Avanzi *et al.* (2013). Notes: EPM = Erosion Potential Method; RUSLE = Revised Universal Soil Loss Equation.

The most alarming results generated by RUSLE can be explained by the LS factor, which showed great variation (0 to 188), due to the relief characteristics in the subbasin, with higher values of the LS factor concentrating in the places of greater slope. The relief has a high influence on the variation in RUSLE results (Beskow *et al.*, 2009). On the other hand, for the EPM model, the impact of the relief (I_{sr}) on the estimates is high, but has less weight in the variation of the results than the coefficients X_a , Y , and H_{yr} (Dragičević *et al.*, 2017). In addition, the high vegetative cover of the sub basin provides a lower value of X_a , which minimizes the results of the EPM model.

According to Ebrahimzadeh *et al.* (2018), the RUSLE classifies regions based on the risk of soil erosion in a reliable way, and making field observations, the author found out that sites with high soil loss estimated by the model were highly susceptible to the erosive process. Based on this statement, and considering that both models presented acceptable errors (< 20%), it can be considered that RUSLE was more efficient in pointing out the areas most susceptible to erosion than the model EPM.

It is worth mentioning that both RUSLE and EPM estimate subbasin soil losses, but cannot measure the actual rate of water erosion or determine the type of soil erosion (Ebrahimzadeh *et al.*, 2018). Therefore, the models are diagnostic tools that should be interpreted critically and combined with other techniques, such as field experiments, when possible.

Finally, even in areas where low soil loss was estimated by the models, soil conservation practices must be introduced to minimize water erosion as much as possible and ensure the future conservation of agricultural systems.

4. CONCLUSION

The models EPM and RUSLE estimated water erosion in the José Lúcio Creek Subbasin with satisfactory precision, with low cost and ease of application.

EPM underestimated soil losses by 15.27%, while RUSLE overestimated them by 19.08%, with alarming results pointing to 4.6% of the study area presenting high erosion rates.

Both models present a similar spatial distribution of soil losses, pointing to the same areas with high erosion rates, supporting the tested hypothesis. The models can be used as tools for planning erosion mitigation practices in the subbasin.

5. ACKNOWLEDGEMENTS

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