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Use of SRTM data to calculate the (R)USLE topographic factor

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ABSTRACT. The topographic factor of the Universal Soil Loss Equation and its revised version (R)USLE are currently calculated by Digital Elevation Models (DEM) integrated to Geographic Information Systems (GIS). However, some countries have no topographic information to calculate DEM. In this study we evaluated the use of the Shuttle Radar Topography Mission (SRTM) data for computing the (R)USLE topographic factor. Furthermore, 90 m SRTM DEM, refined 30 m SRTM DEM and DEMs 30 m and 90 m derived from official topographic maps (1:100,000 scale) were used. Using DEMs the topographic factor was calculated by USLE-2D software. The topographic factor calculated from SRTM data showed greater detail levels (especially in flat areas) than those obtained from topographic maps. The reduction of spatial resolution of DEM-SRTM provided the topographic factor's average rate decrease. SRTM data may be employed in further studies for soil loss predictions. The methodology may be useful in Brazil for the development of soil and water conservation programs.

Keywords: digital elevation model, LS factor, soil and water conservation.

Uso de dados SRTM no cálculo do fator topográfico da (R)USLE

RESUMO. O fator topográfico da Equação Universal de Perda de Solo e da sua versão revisada (R)USLE é atualmente calculado a partir do uso de Modelos Digitais de Elevação (MDE) integrados em Sistemas de Informações Geográficas (SIG). No entanto, alguns países não possuem informações topográficas para calcular o MDE. Assim, neste estudo avaliou-se o uso de dados Shuttle Radar Topography Mission (SRTM) no cálculo do fator topográfico da (R)USLE. Foram utilizados o MDE SRTM-90 m e o MDE refinado SRTM-30 m, além de MDEs de 30 m e 90 m provenientes de cartas topográficas (1:100,000 scale). O software USLE-2D foi usado para calcular o fator topográfico usando os MDEs. O fator topográfico calculado a partir de dados SRTM apresentam melhores níveis de detalhe (especialmente em áreas planas) que os obtidos usando cartas topográficas. A redução da resolução espacial do MDE-SRTM proporciona a diminuição do valor médio do fator topográfico. Os dados SRTM podem ser usados em futuros estudos de predição a perda de solo. No Brasil, isto pode ser útil para o desenvolvimento de programas de conservação do solo e da água.

Palavras-chave: modelo digital de elevação, fator LS, conservação do solo e da água.

Introduction

Models developed to predict soil erosion are used to assess the impact on agriculture, soil and water resources. The Universal Soil Loss Equation (USLE) (WISCHMEIER; SMITH, 1978) is the most used erosion model worldwide and has been integrated into the Geographic Information Systems (GIS) which provides useful information for decision-taking with regard to the planning of water and soil conservation (ERDOGAN et al., 2007; OLIVEIRA et al., 2011). USLE is composed of six factors (rainfall erosivity – R; erodability – K; slope length – L; slope steepness – S; cover and management – C; and conservation practices – P) which result in the estimated average annual soil loss (A).

Factors L and S are treated separately in USLE, although, when analyzed in tandem, they are called the topographic factor (LS). The combination of steepness and slope length associates relief with soil loss. According to Risse et al. (1993), the topographic factor (LS) and the cover and management factor C are the factors that greatly influence the USLE model's overall efficiency. An increase in the topographic factor may produce a higher runoff and erosion rates. In addition, soil loss is considerably more sensitive to changes on slopes than on those in slope length (McCOOL et al., 1987; VAN REMORTEL et al., 2004). Oliveira et al. (2010b) found that the slope factor for plane and smooth relief corresponds to approximately 75% and

84% of the topographic factor in RUSLE and USLE models, respectively.

The topographic factor may be obtained from Digital Elevation Models (DEMs) by the application of USLE on the river basin scale. DEMs correspond to the relief information represented by a numeric data structure comprising the spatial distribution of altitude and ground surface. These models are obtained by interpolation contour lines extracted from a topographic map or by remote sensing images (ALVES SOBRINHO et al., 2010; OLIVEIRA et al., 2010a). In fact, the use of DEMs in GIS has several advantages, such as digital resources (speed, repeatability and computer integration with other databases), a decrease in manual interventions (and thus subjectivity) and the possibility of a parametric approach representing qualitative distinctions from interpretative-based methods (VALERIANO et al., 2006). According to Liu et al. (2009), the accuracy of factor S depends mainly on DEM accuracy and the precision of algorithms. Furthermore, the above authors found that changes in DEM spatial resolution provide variations in the estimated values of soil loss. Liu et al. (2011) concluded that DEM horizontal resolution is very important to calculate factor L, albeit still scantily studied.

When built by remote sensing techniques, such as Interferometric Synthetic Aperture Radar (InSAR), DEMs gain importance because they are obtained by a rapid and accurate topographic data collection technique (RABUS et al., 2003). The Shuttle Radar Topography Mission (SRTM) incorporates InSAR technique and provides available data on a global scale through the United States Geological Survey (USGS). Several studies have been conducted by SRTM to analyze, compare and update information from the surface (FREDRICK et al., 2007; OLIVEIRA et al., 2010a; RENNÓ et al. 2008; VALERIANO et al., 2006).

Some regions in Brazil lack adequate topographic information to calculate DEMs. In this study we evaluated the use of the Shuttle Radar Topography Mission (SRTM) data for computing the (R)USLE topographic factor. Furthermore, 90 m SRTM DEM, refined 30 m SRTM DEM and DEMs 30 m and 90 m derived from official topographic maps (1:100,000 scale) were used.

Material and methods

Study area

The study was carried out in the Salobra basin (~540 km^2), at 20° 12' S - 20° 28' S and 54° 55' W - 55° 16' W, or rather, the transition area between the Cerrado and the Pantanal biomes (Figure 1). Watershed altitude ranges between 200 and 400 meters, with mostly flat relief and an average slope of 2%.

Figure 1. Area under analysis.

Data used

DEMs derived from SRTM data and topographical maps were employed to obtain the topographic factor. The SRTM-DEM was obtained from original information available in South America (spatial resolution of 90 m) and refined SRTM-DEM, with 30 m spatial resolution, available at the morphometric database Topodata (VALERIANO; ROSSETTI, 2012). The refinement of SRTM data from the 3´´ (~90 m) to 1´´ (~30 m) resolution has been accomplished by kriging techniques. This is due to the fact that several studies showed a better performance of derivations after refinement with kriging techniques, and thus good results (VALERIANO et al., 2006; VALERIANO; ROSSETTI, 2012).

DEM was created from the vector data on 1:100.000 scale topographic maps of Campo Grande SF. 21-X-B-II (DSG, 1979) and Palmeiras SF. XB-21-III (DSG, 1988). The maps are represented by 40 m-equidistant contour lines, point features and stream network. From these maps, which are the official basis for the region's topographic studies, DEMs were produced featuring 30 x 30 m and 90 x 90 m rectangular grids using the GIS SPRING software (CÂMARA et al., 1996). DEMs were processed with USLE-2D software (DESMET; GOVERS, 1996) to calculate the topographic factor.

Calculation of factor L

Factor L was calculated by dividing the contribution area by the width over which flow can pass within a grid cell. The width depends on the flow direction and is calculated with the aspect direction (DESMET; GOVERS, 1996) (Equation 1).

$$L_{i,j} = [(A_{i,j} + D^2)^{m+1} - (A_{i,j})^{m+1}]/[x_{i,j}{}^{m}.D^{m+2}.(22,13)^{m}] \quad (1)$$

where:

$L_{i,j}$= slope length factor for a grid cell with coordinates *i,j*;

$A_{i,j}$ = contributing area (m^2) for a grid cell with coordinates *i,j*;

D = grid size (m);

$x_{i,j}$ = outflow direction for the grid cell; m: slope exponent.

Calculation of factor S

USLE-2D software provides four algorithms to calculate the LS association (GOVERS, 1991; McCOOL et al., 1987, 1989; NEARING, 1997; WISCHMEIER; SMITH, 1978). The algorithms of Wischmeier and Smith (1978) – USLE and McCool et al. (1987, 1989) – RUSLE are employed in current essay.

Algorithm of Wischmeier and Smith (1978) – USLE

The exponent (m) of equation 1 was calculated according to Wischmeier and Smith (1978), where: $S < 1\%$, $m = 0.2$; $1\% \leq S \leq 3\%$, $m = 0.3$; $3\% < S \leq 5\%$, $m = 0.4$; and $S > 5\%$, $m = 0.5$. Equation 2, proposed by Wischmeier and Smith (1978), was used to calculate factor S.

$$S = 65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065 \quad (2)$$

where:

θ is the slope in degrees.

Algorithm of McCool et al. (1987, 1989) – RUSLE

The algorithm proposed by McCool et al. (1987, 1989) was applied to obtain the topographic factor and is used in the Revised Universal Soil Loss Equation (RUSLE) (RENARD et al., 1997).

In the USLE, (m) varies according to slope gradient. In the RUSLE, (m) varies according to the ratio of the rill and inter-rill erosion (β).

$$m = \beta/(1+ \beta) \quad (3)$$

β varies according to slope gradient (McCOOL et al., 1989).

$$\beta = (\text{sen } \theta/0.0896) / [3(\text{sen } \theta)^{0,8} + 0.56] \quad (4)$$

The slope angle (S) was calculated following McCool et al. (1987).

$$S_M = 10.8 \text{ sen } \theta + 0.03 \quad (S < 9\%) \quad (5)$$

$$S_M = 16.8 \text{ sen } \theta - 0.50 \quad (S \geq 9\%) \quad (6)$$

where:

θ is the slope in degrees.

Data analysis

Statistical analysis determined the differences between the results obtained from the two data sources used to calculate the topographic factor, SRTM and topographic maps. The difference was calculated for each cell found between the two results with the same spatial resolution, by Wilcoxon signed-rank test to compare means. This occurred because the results did not show normal distribution when assessed by Kolmogorov-Smirnov test.

Since the results are matrices of the same size and geographical position, the value of LS calculated in each cell by one of the methods is compared with its corresponding pair in the other method. The difference between the values of each point is consequently determined. From this matrix, which shows the rate of the differences between the methods, the average (μ_0) is calculated and the null hypothesis is tested (H_0: $\mu_0 = 0$). In other words, there is no significant difference between the methods; if the null hypothesis is rejected, the rate of the differences is significant (H1: $\mu_0 \neq 0$). This procedure has been chosen because cells (pixels) in each position and not just the overall average cell in the watershed may be compared (MINELLA et al., 2010).

Results and discussion

Results provided high variability (Table 1) due to the slope variation which may be straight, concave, convex, or a combination of formats. Hence, the integrated use of DEM in GIS environment facilitates the obtaining of the appropriate topographic factor and enhances the use of erosion models at watershed scale. Minella et al. (2010) found that there is significant gain information with spatial representation method when compared with the traditional one. This is due to the fact that the result is obtained for each unit area (cell), whereas in the traditional method (survey in field) the values correspond to one or more unidirectional measures representative of the area reality.

Table 1. Statistical results of the topographic factor (LS) obtained from the SRTM data (1) and topographic maps (2).

Descriptive Statistics	USLE				RUSLE			
Model	1	2	1	2	1	2	1	2
Spatial resolution (m)	30	30	90	90	30	30	90	90
Average	0.818	0.919	1.313	0.721	0.919	1.009	1.411	0.774
Median	0.498	0.668	0.793	0.277	0.671	0.770	0.985	0.244
Standard deviation	0.914	1.183	1.471	1.014	0.928	1.206	1.416	1.072
Coefficient of variation	1.120	1.290	1.120	1.410	1.010	1.200	1.000	1.390
Comparison of averages								
P- value	0.0016		< 0.0001		< 0.0001		< 0.0001	

The average difference between the cells was significant at 99.99% ($p < 0.01$) (Table 1). Thus, there is a difference between the results from the two data sources studied (SRTM and topographic maps). The above difference occurs because results from SRTM data show a greater degree of detail than those obtained from topographic maps (1:100,000 scale). Since contour lines in topographic maps are 40 m-equidistant, several changes in flat areas on the relief become unnoticeable in DEM. In addition, in the case of a remote sensing-based DEM, each pixel has its own observed rate, whereas in the case of a contour line based on DEM, the rates of all pixels have to be inferred (interpolated) from only two contour lines. Consequently, the remote sensing-based DEM contains more local details than the one derived from the contour lines. Several researchers in Brazil found that SRTM data have best results when compared with DEM by 1:100,000 scale (OLIVEIRA; PARADELLA, 2008; SANTOS et al., 2006) and 1:50,000 scale topographic maps (PINHEIRO, 2006). The use of SRTM data in Brazil is consequently significant since the country's official topographic maps available are usually on a 1:100,000 scale, although there are regions with no topographic information.

The topographic factor derived from topographic maps has greater amplitude when compared to that obtained by SRTM data (Figure 2). In fact, the average values of the results from 30 m SRTM are lower than those from 90 m SRTM. However, in the case of results obtained from topographical maps DEM, the opposite occurs, i.e., the average rates of the topographic factor 30 m DEM are higher than those from 90 m DEM.

When Figure 3A and B are compared with Figure 3C and D and Figure 4A and B are compared with Figure 4C and D, the difference between the results from SRTM and topographic maps occurs owing to a greater detail level in flat areas of the SRTM DEM. The above occurs because the areas with topographic factor zero (LS = 0), presented in Figures 3A and B and 4A/4B, are represented with the factor's detailed rates in Figure 3C and D and Figure 4C and D.

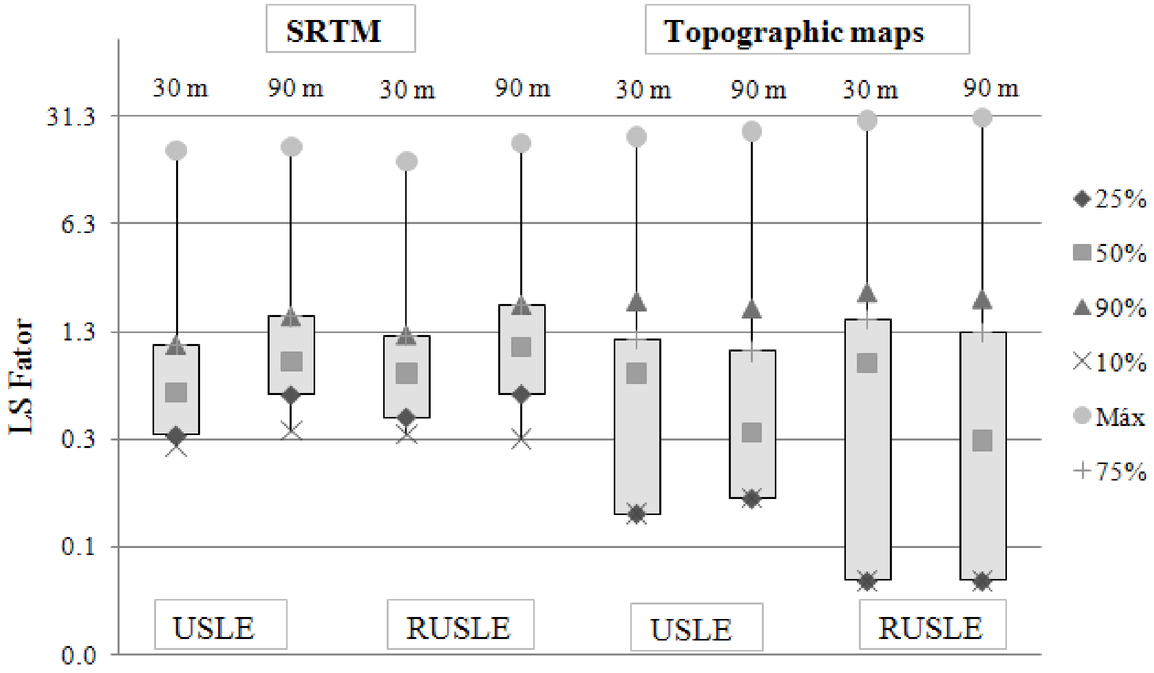

Figure 2. Box and whisker plots calculated for the topographic factor.

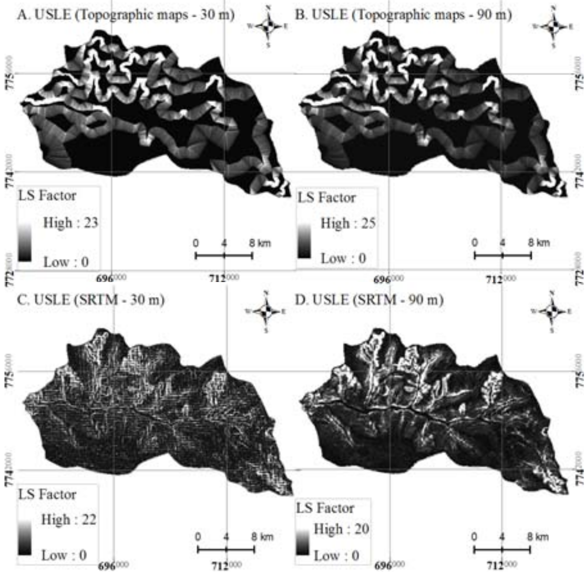

Figure 3. Maps of USLE topographic factor.

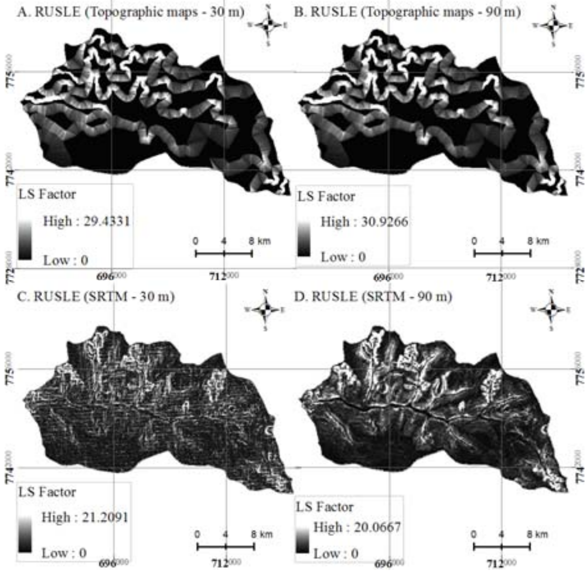

Figure 4. Maps of RUSLE topographic factor.

Liu et al. (2009) found that the average S factor (USLE) significantly decreases when there is an increase of DEM resolution from 1 to 5 m and gradually decreases with an increase of DEM resolution from 10 to 100 m. A decrease in SRTM resolution actually caused a reduction of the topographic factor's average values. However, this trend has not been observed with DEMs derived from topographic maps. The above occurs because SRTM-DEM presents more details than the DEMs obtained from scale 1:100,000 topographic maps. It has also been observed that 90 m DEM obtained from topographic maps has a higher generalization of flat areas (where the topographic factor was zero), thus causing the decrease of the factor's average rates when compared to those of the 30 m DEM. This does not occur in SRTM-DEM since SRTM-DEM has more information on the flat areas. Consequently, the refinement of 90 m SRTM data to 30 m resolution had a larger discreteness of the results and caused a decrease of the topographic factor's average rates.

DEMs 90 m SRTM and 30 m SRTM may be useful alternatives for calculating the topographic factor in watersheds. This information is highly important for new studies on the prediction of soil loss. Furthermore, it also enables the use of (R)USLE models in places with no topographic information or with difficult access. It will be of great help for the development of payments for environmental service programs, on the increase in Brazil. This is due to the fact that watershed services may be measured by the amount or rates of any measures of soil and water, such as runoff, streamflow, erosion and sediment yield since the above are related to the watershed's topographic information (PATTANAYAK, 2004; RODRIGUES et al., 2011).

Conclusion

Current study shows that SRTM data are useful to calculated the topographic factor in watersheds since they enhance the use of (R)USLE models in soil and water conservation planning in Brazil. In addition, SRTM data enable the application of (R)USLE-based models in locations with no topographical data or with difficult access, as in some regions of Brazil.

The topographic factor obtained from SRTM data shows greater detail (especially in flat areas) when compared to results obtained from topographic maps (1:100,000 scale). SRTM data are thus recommended to calculate the topographic factor in Brazil.

DEM spatial resolution directly influences the topographic factor results since decreasing SRTM data spatial resolution caused a reduction of the topographic factor's average rates (from 90 m SRTM to 30 m SRTM).

SRTM data with original information available in South America (spatial resolution of 90 m) and the refined SRTM-DEM, with a spatial resolution of 30 m, available at the database morphometric TOPODATA, may be employed in future studies on soil loss prediction in Brazil. It may help the development of payments for environmental service programs on the increase in Brazil.

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