The USLE model for estimating soil erosion in complex topography areas

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Summary

Soil erosion constitutes a serious problem of land degradation. Mountainous areas located in the humid tropics are more susceptible to soil erosion due to slope features and high precipitation regimen. Water reservoirs located in such areas may lose their storage capacity within a few decades if proper soil management practices are neglected. Considering this process, we used the Universal Soil Loss Equation (USLE) to estimate soil losses in a small catchment (1,895 ha) situated in Southern Brazil (W35°53'/W54°00' and S29°32'/S29°40'). This small catchment responds for about 30% of water consumption in the city of Santa Maria, State of Rio Grande do Sul. Relief is very complex, with elevation and declivity ranging from 137 to 475 m and 0 to 101%, respectively. Soil losses range between 1 and 2 t ha^{-1} $year^{-1}$ in approximately 80% of total catchment area. In general, soil losses under 10 t ha^{-1} $year^{-1}$ are considered low. Only 1% of the area has soil losses greater than 20 t ha^{-1} $year^{-1}$, which is considered moderate. Soil losses over 50 t ha^{-1} $year^{-1}$ which are considered high were not observed. The moderate soil loss-areas are characterized by high declivity (>45%) and shallow soils (<50cm). Permissible soil losses for mountainous areas and shallow soils range between 11 and 25 t ha^{-1} $year^{-1}$ and 2 and 5 t ha^{-1} $year^{-1}$, respectively. We also observed that the LS factor is the major factor controlling the soil loss potential, followed by CP and K factors. Higher soil losses were observed at higher LS factor-sites. Considering our results and available data from previous studies, we conclude that soil losses estimated through USLE are within permissible limits in the small catchment evaluated in our study. The actual 54%-forest land-use may be contributing to reduce annual soil losses. However, occurrence of shallow soils is very expressive. Since these soils have high erodibility and lower permissible limits for soil loss they require special care.

Keywords: USLE, small catchment, land degradation, EUPS, microbacia hidrográfica, degradação das terras.

Introduction

Soil erosion constitutes a serious problem of land degradation. Mountainous areas located in the humid tropics are more susceptible to soil erosion due to slope features and high precipitation regimen (Dadson et al., 2003). Water reservoirs located in such areas may lose their storage capacity within a few decades if proper soil management practices are neglected.

Land use type, topographic features and lithology are among the most important factors determining sediment production within a basin (Romero-Díaz et al., 2007; Verbist et al., 2010). In areas the soil erosion process is at a maximum (Beskow et al., 2009) a sharp reduction of soil productivity occurs. As well water bodies are contaminated with high loads of sediments, fertilizers and pesticides.

The knowledge of environmental features is vital the planning of actions to be implemented. One example Is the Universal Soil Loss Equation (USLE) which gives information about the most problematic areas in relation to soil erosion. When this information is spatialized it is possible to define areas with susceptibility to land degradation (Devicari, 2007).

The USLE model is based on a simple multiplication of factors and the average annual loss of soil (A) is expressed in mass per unit area per time (t ha^{-1} yr^{-1}). The six factors evolved are rainfall erosivity factor (R), soil erodibility (K), slope length (L), slope degree (S), soil cover and crop management (C) and soil conservation practices (P).

The objective of this study was to estimate the potential of soil loss in a small catchment located a hillslope area through the use of GIS techniques, taking into account mainly the occupation, use and type of soils found in the area.

Material and Methods

Our study site is located in Santa Maria County, central region of State of Rio Grande do Sul, in Southern Brazil. Climate is classified as Cfa (Köppen), characterized as subtropical humid without a defined dry season. Mean annual temperature is 19.1 °C and mean annual rainfall is 1712.4 mm (Heldwein et al., 2009). The small catchment evaluated constitutes 60 % of contributing area of a water reservoir responsible for 40 % of water supply in Santa Maria city (figure 1).

Figure 1. Small catchment evaluated in our study. (Google Earth, 2009).

There are several studies to assess the risks of soil erosion, however, this study was based on the USLE, which allows the estimation of annual soil loss in tonnes per hectare per year, given by the product of six factors, According to equation (Wischmeier and Smith, 1978): $A = R * K * L * S * C * P$. The whole procedure for obtaining the factors was conducted in a GIS environment using the software ArcGIS 9.3.1. Factors were multiplied and resulted in the map of soil loss.

The R factor (rainfall erosivity) was calculated from the monthly indices of erosion and expresses the ability of rain to cause erosion in unprotected areas and was considered constant throughout the study area. The K factor is the vulnerability and susceptibility to soil erosion (soil erodibility), which is the reciprocal of its resistance to erosion, and was calculated for each soil class found in the area using the model selected by Denardin (1990).

The factors L (slope length) and S (slope degree) were combined into a single factor (LS). This factor represents the expected relationship of soil loss per unit area at any slope, compared to soil losses in a standard plot of 22.25 meters in length with a 9% slope and estimated by the equation developed by Bertoni e Lombardi Neto (2010).

The factor C (land use and management) was defined through the classification of land use in the image provided by the company DIGITAL GLOBE (Quick Bird satellite) computer application Google Earth (2009) and a value was assigned to each class of land use.

Factor P (conservation practices) refers to the practices of erosion control and was defined as the category of land use, from field notes and literature (Wischmeier e Smith, 1978; Bertoni e Lombardi Neto, 2010).

Results

According to Table 1, about 74% of the area has soil losses bellow 2 t ha^{-1} yr^{-1}. Only 3% of the area has soil losses higher than 20 t ha^{-1} yr^{-1} (Figure 2).

Table 1. USLE-estimated soil loss potential.

Soil loss	Area occupied	
t ha^{-1} yr^{-1}	ha	%
< 1	1062	56
1 – 2	343	18
2 – 5	221	12
5 – 10	114	6
10 – 20	94	5
20 – 50	38	2
> 50	23	1

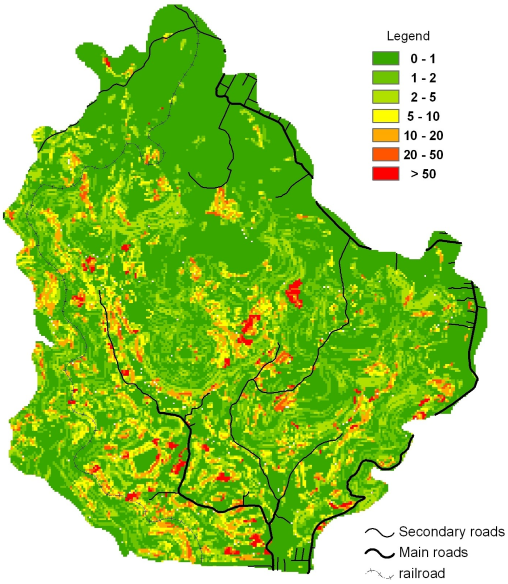

Figure 2. Soil Loss Potential (t.ha^{-1}.yr^{1}) the study area.

Discussion

Establishing tolerance limits for soil losses is a relatively complex study. It must take into account not only the volume of soil lost, but also the rates of soil formation. If a balance between these two processes is set we can defined the tolerance limits.

Because soil classes that display soil losses above 20 t ha^{-1} yr^{-1} are located in areas steeper slopes of the basin and shallower soils, Tomazoni and Guimarães (2005) argue that these soils are more erodible and supporting small removals and that need further attention.

Some studies try to establish some limits through formulas of soil loss tolerance mainly based on the K factor. Mannigel et al. (2002) presents values of tolerance for soil losses of 11.22 t ha^{-1} yr^{-1} for Argissolo Vermelho, 11.62 t ha^{-1} yr^{-1} for Cambissolo Háplico, 14.70 t ha^{-1} yr^{-1} for Neossolo Quartzarênico and 5.74 for Planossolos Háplicos. This information allow us to state that only a few areas with soil associations (Cambissolo – Neossolo) could have been suffering soil losses above the limit of tolerance.

Bertoni and Lombardi Neto (2010) state that the mean values of tolerance for soil losses range from 4.5 to 13.4 t ha^{-1} yr^{-1} for soils with argillic horizons. At soil classes Argissolo Vermelho and Argissolo Bruno-Acinzentado we estimated soil losses bellow 2 t ha^{-1} yr^{-1}. According to Bertoni and Lombardi Neto (2010) this soils classes display soil losses within the permissible limits.

Zhou et al. (2008) claim that among the factors that affect soil erosion, the C and LS factors are the most important since the removal of plant material can cause surface runoff mainly in mountainous areas.

Since crop areas in which soil disturbance is higher appears with little significance, it becomes difficult to identify these possible occasional outbreaks of soil erosion and propose management techniques and soil conservation to improve the situation. Still, Stein et al. (1987) says that degraded areas and agriculture are most critical for providing soil loss, and should be met primarily with conservation techniques, adjusting their ability to use, according to its class of agricultural suitability.

Conclusions

LS factor was the one with higher correlation with estimated soil losses, followed by CP and K factors. Thus, this study argues that there is little freedom from the USLE factors that are merely applications of mathematical formulas (R factor and K) or extracted forms of relief (DEM or SRTM) as the LS factor. However, with factors such as C and P the amplitude of variation becomes larger, affecting at high levels in the final map of soil loss.

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