ABSTRACT

The application of soil erosion models, like the Universal Soil Loss Equation (USLE) through GIS to predict soil loss and to assess crops and soil management has been effectively used to elaborate soil erosion inventories by integration of physiography, soils, landuse/landcover, slope map layers and land evaluation. This paper describes the application of the above technologies in a watershed area at São Paulo-state southwestern region, Brazil. Sugarcane and pasture are the main land use comprising almost 90% of the area. The soil loss rates varied from 0.1 t.ha$^{-1}$.yr$^{-1}$ in forest areas to 30 t.ha$^{-1}$.yr$^{-1}$ in sugarcane areas. The erosion risk map obtained through USLE showed that 54% of the area was classified as medium to high erosion risk.

INTRODUCTION

Land use changes, in São Paulo state, Brazil, have caused accelerated land degradation processes, due to soil erosion. Lal and Stewart (1992) reported that between 5 to 7 million hectares of arable land are lost every year via soil degradation. Soil erosion is now one of the most serious environmental problem in agricultural areas in Brazil. The Governmental incentives for alcohol production from sugarcane increased the extent of the agricultural area, with consequences to the environment due to monoculture and soil degradation. The intensive monoculture endangers the watersheds and results in massive soil erosion, declining soil productivity and silting up rivers channels (Trejo, 1997). Erosion may be accelerated as a result of two factors: (1) improper productive soil management and (2) marginal land exploitation (Dregne, 1982). The lack of adequate land use planning and soil knowledge have been one of the major problems to develop soil conservation policies to avoid environmental degradation. The technologies of remote sensing and geographical information system (GIS) have made available powerful tools to establish soil conservation and land use planning strategies at the watershed scale. A GIS can improve the understanding of land use planning and decision-making (Trejo, 1997). The application of soil erosion models, like the Universal Soil Loss Equation-USLE (Wishmeyer & Smith, 1978), through GIS to predict soil loss and to assess crops and soil management has been effectively used to elaborate soil erosion inventories by integration of physiography, soils, landuse/landcover, slope map layers and land evaluation. Considering the above statements, this study research the application through GIS of a soil erosion model to evaluate soil losses and its relationship with land cover in a watershed scale.
MATERIAL AND METHODS

The present research was carried out at the Lajeado watershed, an 1,263 ha area at São Paulo-state southwestern region, Brazil (21° 25’S and 50° 05’W), located in a sugarcane growing region. The first step consisted in creating a digital data bank in Ilwis - Geographical Information System - containing all the information required to evaluate the land use planning. The basic information required to the objectives of this study were:

- Detailed Topographic map (1:10000)
- Detailed Soil Map (1:10000)
- Land Use Map
- Climate Data (mean and annual monthly precipitation)
- USLE-factor parameters

The flow chart presented in Figure 1, summarizes all the acquired data and the method of integration in GIS to assess land use planning and soil loss rates.

**FIGURE 1. Application of USLE factor through GIS**

**Soil Map**

The methodology is based on a soil survey resource inventory, which comprises aerial photograph interpretation, field survey and laboratory work. In the total, 35 soil samples were collected in 0-20cm and 80-100 cm depth. Chemical and physical analyses were performed. Soil survey inventory showed that Ultisol and Alfisol (Table 1) are the predominant soil types, comprising 90% of the total area and the predominant parent material is sandstone. These soils are very susceptible to erosion due to the great difference in clay content between A and B horizons.
Table 1. Soil types occurrence, K-Erodibility factor and T- maximum tolerance of soil loss accepted

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Area (ha)</th>
<th>K-factor (M.J.mm.ha⁻¹ h⁻¹)</th>
<th>T-factor (T.ha⁻¹.yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latossolos Vermelho Vermelho Escuro LE (Oxisol)</td>
<td>202.26</td>
<td>0.0178</td>
<td>15.0</td>
</tr>
<tr>
<td>Latossolos Vermelho Amarelo – LV(Oxisol)</td>
<td>103.07</td>
<td>0.0172</td>
<td>14.2</td>
</tr>
<tr>
<td>Podzólico Vermelho Escuro – PE (Alfisol)</td>
<td>80.49</td>
<td>0.0357</td>
<td>7.7</td>
</tr>
<tr>
<td>Podzólico Vermelho Amarelo distrófico – PVd (Ultisol)</td>
<td>176.85</td>
<td>0.0419</td>
<td>7.7</td>
</tr>
<tr>
<td>Podzólico Vermelho Amarelo distrófico/mesotrófico – Pve (Ultisol)</td>
<td>614.19</td>
<td>0.0419</td>
<td>7.7</td>
</tr>
<tr>
<td>Solos Hidromórficos – (Aquents)</td>
<td>88.1</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1263.00</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Topographic Map**

The relief of the study area is characterized by undulate hills with altitudes ranging between 410 and 520 m. A detailed topographic map (with vertical distance of level curves between 10 meters) was digitized in Ilwis. A contour interpolation was performed to generate the Digital Elevation Model (DEM). Slope and slope length map were directly obtained from DEM. Slope length map was obtained according to the equation:

\[ L = 740.05S^{1.2012} \]  
where: \( L \) = Slope length and \( S \) = Slope (%)  

**Land Use Map**

One quadrant of digital Landsat Thematic Mapper image (Path:222, Row 75, bands TM3, TM4, TM5 and TM7) was acquired in 1998. Image processing was performed using ILWIS. The image enhancement techniques consisted of linear contrast modification, image filtering operations and band ratio. A principal component analysis was performed on the TM bands. Considering the characteristics of the vegetation cover in the study area that presents land use classes in different development stages we have calculated the normalized vegetation index, using the following band ratio:

\[ IVN = 128*[1+(TM4-Tm3)/(TM4+TM3)] \]  

Using a color composition (TM bands 4, 3 and 7), training areas were sampled for the image classification. Ground information, collected with GPS, showed that land cover in the area include: Forest, Reforestation, Sugarcane, Pasture, Corn, Coffee and some fruit-bearer. A MAXVER supervised classification was applied. Some confusion about land use classes were reduce with visual analysis interpretation performed on the color composition image and on the aerial photographs.

**USLE-factors**

The Universal Soil Loss Equation (Wischmeier & Smith, 1978) was used to estimate the average amount of soil loss and to elaborate erosion risk map and land use planning map. In this case, the USLE parameters were obtained as follow:

1. Rainfall intensity (R-factor) – It was considered as homogeneous for the watershed with a value of 6757MJ.mm/ha.h
2. Soil erodibility (K-factor) was calculated according to Bertoni & Lombardi Neto (1992)
3. Topography (LS-factor) was determined by the equation: \( LS = 0.00984L^{0.63}S^{1.18} \) (Bertoni and Lombardi Neto, 1992)
4. \( C \) (Land-use factor) was obtained from the land-use map according to Bertoni & Lombardi Neto (1992)
5. \( P \) (P-factor) was obtained by the methodology proposed by Lombardi Neto (in preparation), and varied between 0 to 1.
**Erosion Risk**

The watershed erosion risk \( E \) considered the relationship between the Maximum Acceptable Soil Loss Tolerance \( T \) and the Natural Erosion Potential \( \text{NEP} \), according to the formula:

\[
E = \frac{T}{\text{NEP}}
\]

(3)

where: \( \text{NEP} = R \cdot K \cdot LS \)

**Land Use Planning**

Land Use Planning Map was obtained by overlaying Land Use and the Land Capability Map. This process took into account the Erosion Risk Map. Land Capability classification is a broad grouping of soils based on their limitations. It serves as a guide to assess the suitability of land for cultivation, grazing and other uses. It was made a comparison between the actual land use and the land use suggested by the land capability classification, according to the previous limitations of soil physical and chemical properties and slope gradient. This comparison results in another map called Land Planning Map, that summarizes the conflicts between the land use and the land capability map.

**RESULTS**

The land use map obtained through digital image processing and visual interpretation of satellite image and aerial photographs is presented in Figure 2. Sugarcane is the main land use, occurring in 58% of the total area, followed by pasture with 29%. Others occupations, like coffee and banana were observed. The area of native forest is little expressive and reduced to 5% of the total area. The intensive soil mechanization associated with sugarcane production, the natural limitation (high soil erodibility and slope) and the great pressure of occupation requires a soil conservation prioritizing in sugarcane areas. Soil loss rates varied from 0.1 t.ha\(^{-1}\).yr\(^{-1}\) in forest areas to 30 t.ha\(^{-1}\).yr\(^{-1}\) in sugarcane areas (Figure 3). Compared to the maximum tolerance of soil loss (Table 1), the average rates for sugarcane (30 t.ha\(^{-1}\).yr\(^{-1}\)) were large and should be reduced. This problem is critical in those areas with slope higher than 9%.

![FIGURE 2. Land use map of the watershed](image-url)
The erosion risk map, presented in Figure 4, showed that 54% of the area presents a medium to high erosion risk levels and approximately 30% of sugarcane production occurs in these areas.

The Sustained Land Capability, obtained by overlaying soil and slope maps (Figure 5), showed that almost 53% of the area are class IVe with limitations of soil and erodibility, requiring the adoption of careful management practices. The Land Capability Map and the Land Use Map were overlaid to generate the Land Planning Map, presented in Figure 6. This new layer, produced through GIS analysis, is very useful to decision making in the process of land use planning. This analysis indicates areas which presents an appropriated land occupation and where soil loss associated with the land use is not higher than the acceptable erosion tolerance. The watershed has 34% of the area classified as “Appropriated with restrictions”. Normally these areas occur in areas having slope gradient between 9-12% and soils with high erosion susceptibility, besides being cultivated with sugarcane. This land use is known to require specific management practices to reduce the soil loss.
CONCLUSIONS

The methodology allowed the indication of priority areas for decision-making intervention. Sugarcane production in those areas with high natural limitation, requires careful practices to avoid high soil loss rates. In almost 34% of the area soil loss is higher than the accepted tolerance value. Furthermore, the use of USLE through Geographical Information System confirms the potential of this technique in the process of planning, implementation and monitoring sustainable land use.

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REFERENCES


