LAND PLANNING FOR SUSTAINABLE DEVELOPMENT IN WATERSHEDS USING GEOGRAPHICAL INFORMATION SYSTEM

Jener Fernando Leite de MORAES*, Pedro Luiz DONZELI*, Francisco LOMBARDI NETO*, André Ricardo MELO, Hélio do PRADO*
*Instituto Agronômico de Campinas, Brazil
jfmoraes@barao.iac.br

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ABSTRACT

The lack of adequate land use planning and soil knowledge have been one of the major problems to develop soil conservation politics to avoid environmental degradation in Brazil. The application of soil erosion models, like the Univesal 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. The main soil types of the area (Ultisol an Alfisol) are very susceptible to erosion due to the great difference in clay content between A and B horizons. 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. Approximately 30% of sugarcane production occur in theses areas which indicates that a suitable land use for these areas should consider careful management practices.

RÉSUMÉ

L'absence de planification de l'utilisation des terres adéquate et d'une connaissance des sols ont limité le développement de politiques de conservation du sol visant d'une manière générale à limiter la dégradation de l'environnement au Brésil. Des modèles d'érosion des sols, dérivés de l'équation universelle de perte de sol (USLE) ont été efficacement utilisés pour prévoir les pertes de sol et effectuer des bilans sur de vastes surfaces grâce à l'utilisation de Systèmes d'Informations Géographiques (SIG). Les SIG permettent l'intégration d'information sur la morphologie des paysages, les sols, et leur utilisation . Cet article décrit l'application de tels outils au niveau d'un bassin versant de la région sud-ouest de l'état de São Paulo (Brésil). Les principaux types de sol rencontrés (Ultisol et Alfisol) sont très susceptibles à l'érosion du fait d'un fort gradient textural sur le premier mètre. La canne à sucre et les pâturages sont les principales utilisation des terres, couvrant presque 90%. Les taux de perte de sol sont passés de 0,1 $t.ha^{-1}.yr^{-1}$ dans les zones de forêt à 30 $t.ha^{-1}.yr^{-1}$ dans les zones de canne à sucre. La carte des risques d'érosion obtenue par USLE montre que 54% de la zone d'étude présentent des risques d'érosion moyens à forts où approximativement 30% de production de la canne à sucre à lieu. Une utilisation adéquate de la terre pour ces zones doit considérer un management adapté.

1 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 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, 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 politics 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 the processes 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.

2 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 (Figure 1). 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

Figure 1. Location of the study area

The flow chart presented in Figure 2, resume all data acquired and how they were integrated in GIS to assess land use planning and soil loss rates.

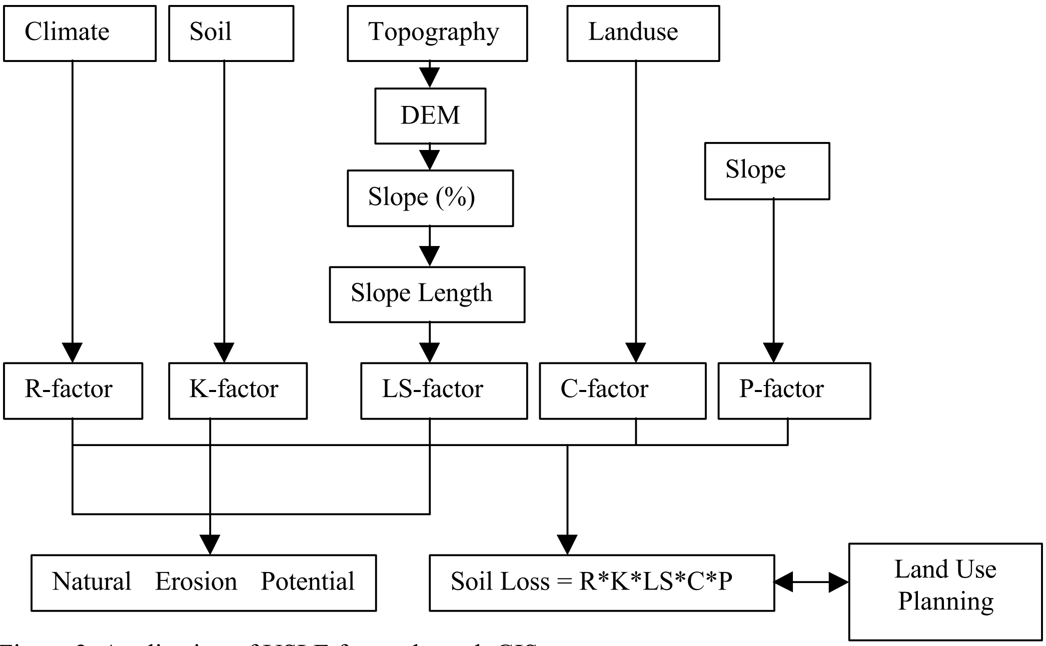

Figure 2. Application of USLE factor through GIS

* Ilwis – Integrated Land and Water Information System. ITC

2.1 Soil Map

The methodology iniciates by a soil survey resource inventory comprising aerial photograph interpretation, field survey and laboratory work. In 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 the sandstone. These soils are very susceptible to erosion due to the great difference in clay content between A and B horizons.

Soil Type	Occurrence (ha)	K-factor $M.J.mm.ha^{-1} h^{-1}$	T-factor $(T.ha^{-1}.yr^{-1})$
Latossolos Vermelho Vermelho Escuro – LE (Oxisol)	202.26	0.0178	15.0
Latossolos Vermelho Amarelo – LV – (Oxisol)	103.07	0.0172	14.2
Podzólico Vermelho Escuro – PE – (Alfisol)	80.49	0.0357	7.7
Podzólico Vermelho Amarelo distrófico – PVd – (Ultisol)	176.85	0.0419	7.7
Podzólico Vermelho Amarelo distrófico/mesotrófico – PVe – (Ultisol)	614.19	0.0419	7.7
Solos Hidromórficos – (Aquents)	88.1	---	---
TOTAL	1263.00		

Table 1. Soil types occurrence, K-Erodibily factor and T- maximum tolerance of soil loss accepted

2.2 Topographic Map

The area topography 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 obtained from DEM. Slope length was obtained according to the equation:

$$\mathbf{SL = 740.05*S^{-1.2812}} \qquad \textbf{(1)}$$

where: SL = Slope length and S = Slope (%)

2.3 Land Use Map

One quadrant of digital Landsat thematic map image (Path:222, Row 75) 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 3, 4, 5 and 7. 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:

$$\mathbf{IVN = 128*[1+(TM4-Tm3)/(TM4+TM3)]} \qquad \textbf{(2)}$$

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.

2.4 USLE-factors

The Universal Soil Loss Equation (Wischmeier & Smith, 1978) was used to estimate the average extent of soil loss and to elaborate soil 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: $LS = 0.00984*L^{0.63} *S^{1.18}$ (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.

2.4.1 Erosion Risk

The watershed erosion risk (E) considered the relationship between the Maximum Tolerance of Soil Loss Accepted (T) and the Natural Erosion Potential (NEP) according to the formula:

$$E = \frac{T}{NEP} \tag{3}$$

where: NEP = R*K*LS

2.4.2 Land Use Planning

Land Use Planning Map was obtained through overlaying Land Use and the Land Capability Map. The Erosion Risk Map was considered in this process too. 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

3 RESULTS

The land use map obtained through digital image processing and visual interpretation of satellite image and aerial photographs is presented in Figure 3. The sugarcane is the main occurrence with 58% of total area, followed by pasture with 29%. Others occupations like coffee, 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 and the natural limitation (high soil erodibility and slope) and the great pressure of occupation requires a soil conservation priorizating in sugarcane areas.
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 (Figure 4). Compared to the to the maximum tolerance of soil loss (Table 1) mainly average rates for sugarcane (30 $t.ha^{-1}.yr^{-1}$) is large and should be reduced. This problem is critical in those areas with slope larger than 9%.

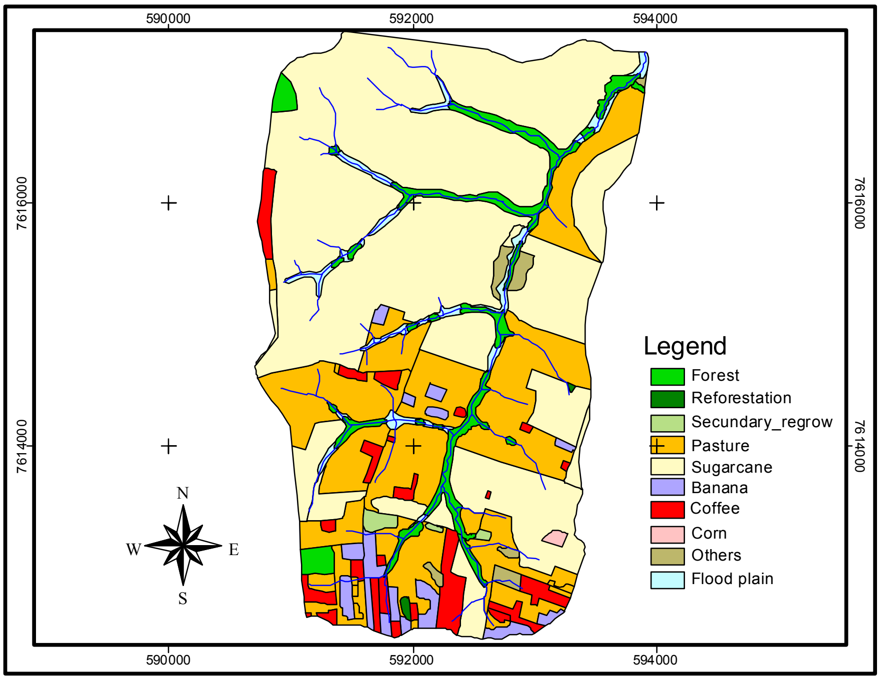

Figure 3. Land use map of the area

The erosion risk map, presented in Figure 5, showed that 54% of the area presents a **medium to high** erosion risk and approximately 30% of sugarcane production occurs in these areas.

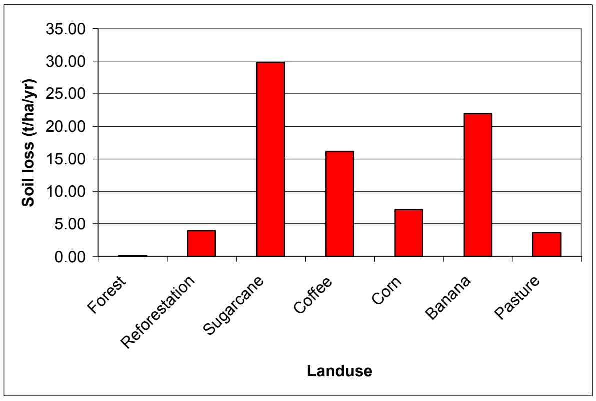

Figure 4. Soil loss according to the land use type

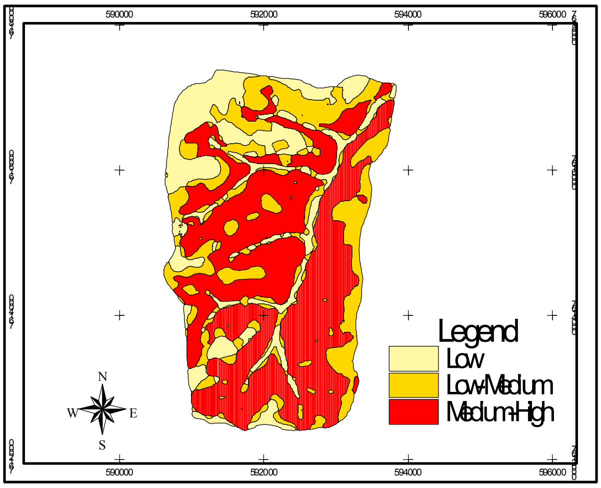

Figure 5. Erosion risk map

The Sustained Land Capability, obtained through overlaying soil and slope maps (Figure 6) showed that almost 53% of the area belongs to class IVe with limitations of foil and erodibility, being necessary the adoption of careful management practices. Land Capability Map and the Land Use Map overlaying, generated the Land Planning Map, presented in Figure7. This new layer, produced through GIS analysis is very useful to decision making in the process of planning. This analysis indicates areas which presents a appropriated land occupation. In other words, the land occupation is classified as appropriated when soil loss associated with the land use is not higher the accepted erosion tolerance. The watershed has 34% of the area classified as "**Appropriated with restrictions**". Normally these areas occur in a slope gradient between 9-12% and soils with high erosion susceptibility, besides to be cultivated with sugarcane that requires specific management practices to reduce the soil loss.

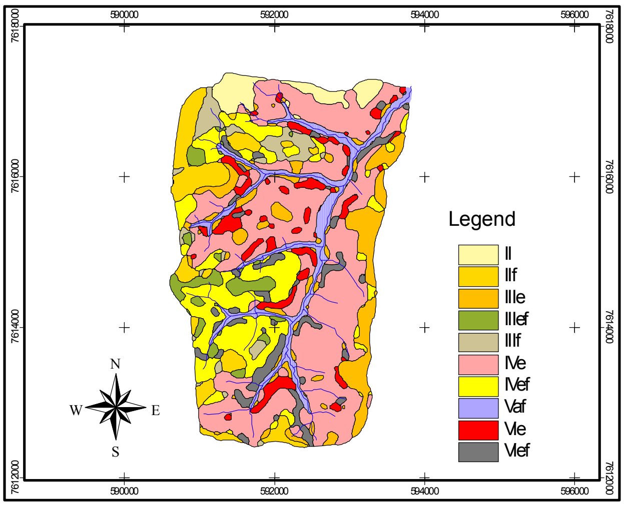

Figure 6. Land capability map

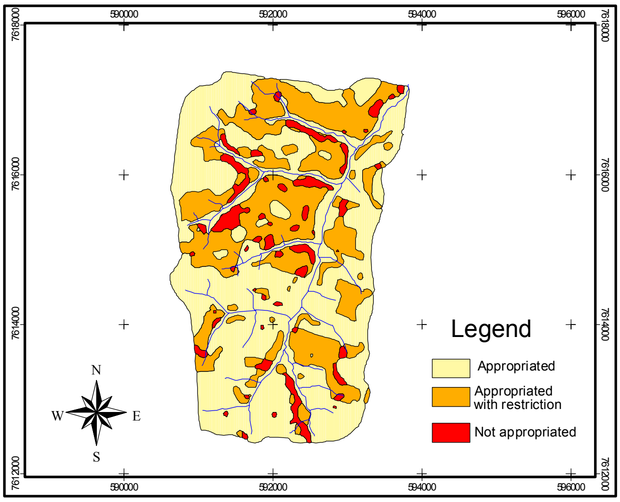

Figure 7. Land use planning map

4 CONCLUSIONS

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

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