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Soil losses in the Cedro river basin/MG based on the sensor TM/LANDSAT-5 images

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ABSTRACT: Changes in land use and land coverage can cause degradation due to soil loss from the drag of particles, ultimately leading to siltation of rivers and irreversible damage. Thus, the objective of this study was to determine the soil loss in the basin of the Cedro river, north of Minas Gerais, Brazil, using the Universal Soil Loss Equation (USLE) and time series of LANDSAT-5/TM satellite images. The methodology included the acquisition and classification of LANDSAT-5/TM images for the years 1984, 1990, 2000 and 2011. Maps corresponding to the following parameters were generated: erosivity; erodibility; slope degree; slope length, map of soil use and occupation and conservation practices. The final soil loss map was drawn up in the environment LEGAL/SPRING/version 5.1.8 through map algebra. Soil losses in the basin were moderate for all years in the case of areas with slight slopes and with good vegetation cover. In turn, soil loss was very high in the case of areas with slopes above 20% and with little vegetation cover. Soil loss for the year 1984 was lower, while major losses were recorded for the years 1990 and 2000.

Keywords: geographic information system, universal equation of soil loss, environmental degradation.

Perdas de solo na bacia do rio Cedro/MG a partir de imagens do sensor TM/LANDSAT-5

RESUMO: Mudanças no uso e na cobertura do solo podem provocar degradação em decorrência da perda de solo proveniente do arraste das partículas, resultando no assoreamento dos rios, o que causam danos muitas vezes irreversíveis. Portanto o objetivo do trabalho foi determinar a perda de solo, por meio da Equação Universal de Perda do Solo (EUPS), na bacia do rio Cedro, norte de Minas Gerais, a partir de séries temporais de imagens de satélite LANDSAT-5/TM. Na metodologia foi inclusa a aquisição e classificação das imagens LANDSAT-5/TM para os anos de 1984, 1990, 2000 e 2011. Foram gerados mapas correspondentes aos parâmetros: erosividade, erodibilidade, grau de declive, comprimento do declive, mapa de uso e ocupação do solo e práticas conservacionistas. O mapa final de perda de solo foi elaborado no ambiente LEGAL/SPRING/versão 5.1.8 por meio da álgebra de mapas. As perdas de solo na bacia, para todos os anos, foram moderadas, para áreas mais suaves e com boa cobertura vegetal; até perda muito alta, para áreas de relevo com declividade superior a 20% e com pouca cobertura vegetal. A perda de solo para o ano de 1984 foi menor, enquanto que, para os anos de 1990 e 2000 foram registradas maiores perdas.

Palavras-chave: sistema de informação geográfica, equação universal de perda de solo, degradação ambiental.

1. INTRODUCTION

Water laminar erosion consists in the homogeneous removal of the superficial portion of the soil (GUIMARÃES et al., 2011). Such soil loss in river basins happens due to natural processes and is enhanced by human intervention that causes imbalance in soil-climate-vegetation relationships, leading to instability of the system and posing a strong influence on processes, forms and evolution of the slopes (BRASIL, 1983; GUERRA, 2003; GUERRA; CUNHA, 2006).

In Brazil, the soil has not been correctly used, especially in hillside areas, as slopes represent one of the factors that trigger increased erosion and consequent environmental degradation (GUERRA 2003; SILVA et al., 2012).

Concomitantly, basins that have little vegetation present higher soil erosion. This promotes silting and reduces groundwater recharge, leading to a lack of water in the springs in periods of drought and reducing the flow of the springs, which are often used by local populations for irrigation and water supply (TUNDISI; TUNDISI, 2005).

In agriculture, the use and occupation of land in hydrographical basins inappropriately increase soil degradation, promoting the drop in productivity as a result of the removal of nutrients necessary for the development of cultivated species. Water quality is also affected due to carrying of waste such as pesticides and organic and inorganic materials trapped in soil particles into the river system, polluting it (SANTOS et al., 2010).

According to Vale Júnior et al. (2009), soil loss through erosion causes decline of the plant yields, increasing production costs, decreasing, consequently, the profitability of the crop. These and other further damage together influence the quality of life on Earth. For this reason, soil loss is considered one of the largest and most alarming environmental problems. Campos et al. (2008) claim that knowledge on soil loss and the influence of each factor on this process strengthen the understanding of the landscape development and improve the understanding of the performance of agricultural production.

Thus, the prediction of soil loss through erosion represents an important tool to quantify environmental degradation, as well as it is a guide in the systematic planning of basins, and it can be evaluated with the use of Remote Sensing and Geographic Information Systems (MENDONÇA et al., 2014). Such technologies can automate tasks that were previously carried out manually, making it easier to conduct complex analysis and allowing analysis that assist decision-making (PRADO; NÓBREGA, 2005; TOMAZONI; GUIMARÃES, 2005; WEILL; SPAROVEK, 2008).

Therefore, studies seeking to understand how the process of degradation occur over a historical series, diagnosing the problems caused to the environment and the consequences for the local community, and estimating the intensity of each of the main factors influencing soil loss, through the combination of equations with geoprocessing techniques, are very important (PAES et al., 2010).

According to Miqueloni et al. (2012), the widespread erosion model is the Universal Soil Loss Equation (USLE). This estimates the average soil loss for long periods of time caused by laminar water erosion and is a practical model because it uses parameters that are easy to obtain. This indirect model is the most currently employed in this context, and it is observed in various scientific research studies such as CORREA et al. (2007), AVANZI et al. (2008), SILVA et al. (2010), NEVES et al. (2011), ZHANG et al. (2011) and MENESES (2014).

In this context, the objective of the present study was to determine the loss of soil from the Cedro river Basin/MG from a time series of LANDSAT-5/TM satellite images, through the Universal Soil Loss Equation.

2. MATERIAL AND METHODS

2.1. Study area

The Cedro river Basin/MG, Figure 1, is located in the northern region of Minas Gerais, in the city of Montes Claros/MG. The spring is located in the district named Nova Esperança, in the community known as Buriti do Campo, 40 km away from Montes Claros, located within the coordinates 16°42'24.12" S and 44°01'24.12" W, and its mouth is located within the coordinates 16°39'51.84 "S and 43°50'59.12" W. The basin covers an area of 172 km² and the main river (Cedro river) has a length of 25.6 km and has areas of supression and re-appearance along its route and drains into the left bank of the Vieira river. The Cedro River is important in the city of Montes Claros because its sources are used by the Sanitation Company of Minas Gerais (COPASA) for the city's water supply.

According to Köppen, the region is classified as Aw, characterized by a warm climate and rainfall concentrated in the summer, with dry winters. The average annual rainfall is 1060 mm with rainfall concentrated in the period from October to March, with average annual temperature of 24ºC. According to the IBGE (2004), the region has vegetation classified as deciduous Cerrado and semideciduous Cerrado with a few portions of 'superemifólio' Cerrado, which is characterized as a transitional area between forest and open vegetation.

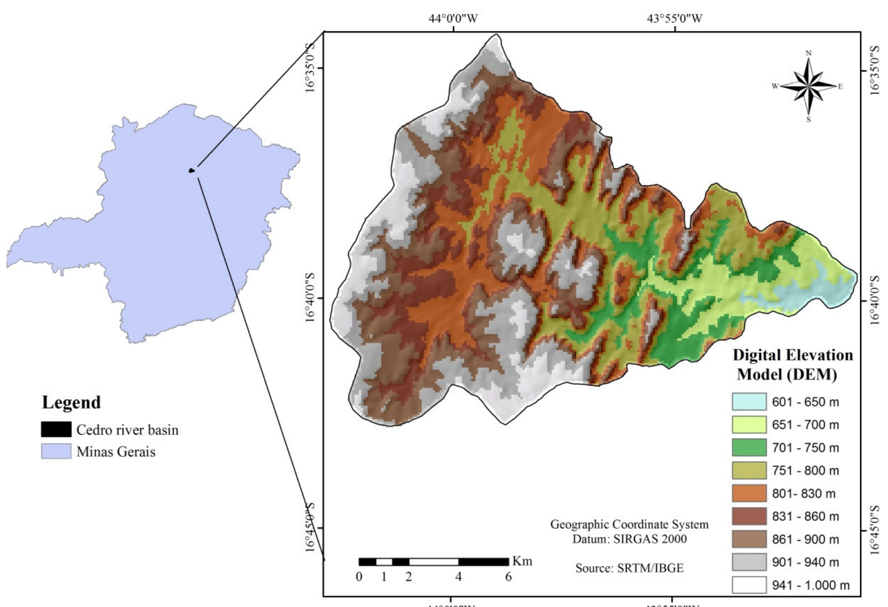

Figure 1. Spatial location of the Cedro river Basin/MG in the state of Minas Gerais highlighting the city of Montes Claros.
Figura 1. Localização espacial da Bacia do rio Cedro/MG no estado de Minas Gerais destacando o município de Montes Claros

2.2. Determination of the USLE parameters for the years 1984, 1990, 2000 and 2011

The model used to estimate soil loss for the Cedro river Basin/MG through water laminar erosion was the Universal Soil Loss Equation (USLE) - (Eq. 1) developed by Wischmeier; Smith (1978) (BERTONI; LOMBARDI NETO, 2008).

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where:

A - soil loss in t ha^{-1};
R - rain factor in MJ mm ha^{-1} $year^{-1}$;
K - soil erodibility factor;
L - slope length factor;
S - slope degree factor;
C - cover and management factor; and,
P - conservationist practice factor .

2.2.1. Rain erosivity factor - R

To obtain the erosivity factor (R), a time series of 27 years of monthly precipitation represented by the years 1980-1983 and 1989-2011 from the INMET Meteorological Station (2012) was used. The years 1984 - 1988 were not taken into account because of the lack of data in this period. We used the method adjusted by Bertoni and Lombardi Neto (2008) in order to obtain the erosivity factor (R) expressed by the Eq. 2:

$$R = \sum \left[67.355 \left(\frac{r^2}{P} \right) 0.85 \right] \quad (2)$$

where:

R - index of erosion caused by rain, Mj mm ha^{-1} $year^{-1}$;
r - average of the total monthly rainfall (mm); and,
P - average of the total annual rainfall (mm).

2.2.2. Soil erodibility factor - K

Erodibility is the susceptibility of a particular type of soil to water erosion. For this, the type of soil of the basin was obtained in the Soil Map of the State of Minas Gerais, with respective extended legend, in the scale of 1: 500,000 (UFV; CETEC; UFLA; FEAM, 2010). The types of soils found in the basin are: HAPLIC CAMBISOL Typical dystrophic (CXB), RED-YELLOW LATOSOL Typical distrophic with clayey texture (LVAd clayey texture) and medium texture (LVAd medium texture), HAPLIC NITOSOL Typical dystrophic (NXd), and typical eutrophic (NXe), and the CXb was the predominant type of soil (EMBRAPA, 2013). Erodibility values for soil types in the basin are described in Table. 1.

2.2.3. Topographical factor - LS

L and S factors are jointly assessed in the USLE, and they refer to the length of the hill and its slope. The map for the LS factor was prepared according to the Eq. 3, proposed by Bertoni; Lombardi Neto (2008).

$$LS = 0.00984 \times L^{0.63} \times D^{1.18} \quad (3)$$

where:

C - length of the hill in meters; and
D - Degree of the slope in percentage.

Table 1. Erodibility values for different soil types.
Tabela 1. Valores de erodibilidade para os diferentes tipos de solo.

Soil types	K (t h MJ^{-1} mm^{-1})
CXb	0.0237
LVAd clayey texture	0.0171
LVAd medium texture	0.0100
NXd	0.0197
NXe	0.0230

Source: CAROLINO DE SÁ et al. (2004); (EMBRAPA, 2013).

The length of the hill was obtained using the method proposed by Villela; Mattos (1975), according to Eq. 4:

$$L = \frac{A}{4l} \quad (4)$$

where:

L - slope length factor;
A - basin area in m²; and,
L - sum of the length of all watercourses in the basin (m).

2.2.4. Cover and soil management factor - C and conservation practices - P

The C factor relates the soil loss according to the type of cover in the soil. It may reach values close to zero in the case of virgin forest and values close to one in the case of bare soil (no practical support). The P factor is the ratio of soil loss with a practice of support in relation to the corresponding loss without this practice.

For the preparation of the map of use and land cover, images were acquired from the LANDSAT-5 sensor TM satellite taken in August because this month has lower incidence of clouds, of the orbit/point 218/71 and 218/72, which comprises the municipalities of Montes Claros and Coração de Jesus in the years 1984, 1990, 2000 and 2011. Image processing was carried out in ENVI 4.2 software® ESRI and included the georeferencing from GeoCover (Global Land Cover Facility) images provided by NASA (National Aeronautics and Space Administration). The method used was the selection of 12 control points of the GeoCover image and the same points in the LANDSAT-5/TM image for georeferencing. After this step, the mosaic of scenes 218/71 and 218/72 was generated and, then, the cut of the basin through the vector file was proceeded.

The clipping of the basin corresponding to the studied area is situated in the geographical coordinates 16°39'51.843" S, 43°50'59.124" W and 16°42'24.12" S and 44°1'24.12" W. The images were standardized for UTM projection and Datum SIRGAS 2000. After these procedures, a RGB-453 colored composition was made thein SPRING 5.1.8 software (CAMARA et al., 1996) as well as the unsupervised classification by regions. For this, we carried out the segmentation of images with similarity of 30 and area of 50. The chosen classifier algorithm was ISODATA with 5 interactions and the acceptance threshold for determining the classes of use and occupation was 95%.

The C and P values for the study area were defined according to data from Table 2, in association with the thematic map of the cover and soil management factor in the years 1984, 1990, 2000 and 2011 in theLEGAL/SPRING 5.1.8 environment.

Table 2. C values according to coverage and soil management.
Tabela 2. Valores de C em função da cobertura e manejo do solo.

Land cover classes	Factor C	Factor P
Dense vegetation	0.010	1
Pasture	0.03000	1
Agriculture/Reforestation	0.04910	0.5
Outcrop	0.0001	1
Soil exposed	1	1

Source: FUNJIHARA (2002).

2.3. Determination of the final map

The maps corresponding to each parameter were prepared at the LEGAL/SPRING 5.1.8 environment through the weighting algorithm and the final map for the estimated soil loss for the entire basin was developed through the multiplication algorithm of the same program, corresponding to each year analyzed.

3. RESULTS AND DISCUSSION

The erosivity found for the Cedro river Basin/MG, Table 3, was 6.993,77 Mj mm ha^{-1} year^{-1}. Such erosivity value corresponds to all years studied, since the historical average precipitation was the same for the respective periods. As the northern region of Minas Gerais is characterized by the rainfall concentrated in the period of November through March, featuring high intensity and short duration, the highest values of erodibility were found for the months of November, December and January (Table 3), which is considered the rainy season in the region.

The erodibility value found, 6.993,11 Mj mm ha^{-1} year^{-1}, was very similar to the annual average erodibility estimated by Lopes et al. (2011), 6.328 Mj mm ha^{-1} year^{-1} for the Varjota river watershed in Ceará. Paes (2010) found a value that is 33% value higher than the Cedro river Basin/MG to the basins in the municipality of Santa Rita do Sapucaí, in southern Minas Gerais, as this is a region with highest rainfall levels.

The predominant soil was Cambisol, corresponding 66.58% of the area; Latosols corresponded to 19.09% of the area; and Nitosols occupied 14.33% of the area (Figure 2). Cambisols and eutrophic Nitosols are soil types that have high susceptibility to erosion, and these together represent 79.89% of the basin.

Table 3. Monthly average precipitation (P) and mean interval of monthly erosivity (EI).
Tabela 3. Precipitação média mensal (P) e intervalo médio de erosividade mensal (EI).

Month	P (mm)	EI (Mj mm ha^{-1} year^{-1})
January	188.26	1,336.33
February	104.54	491.62
March	147.57	883.34
April	38.83	91.28
May	8.40	6.76
June	4.47	2.31
July	0.67	0.09
August	1.70	0.45
September	17.89	24.46
October	74.81	278.34
November	210.93	1,621.39
December	256.27	2,257.40
Total	1,054.34	6,993.77

In turn, Latosols tend to have low susceptibility to erosion, due to its high permeability when associated with flat and slightly undulated terrains (MENEZES et al., 2009).

While assessing the relief (Figure 3), it was observed that this is very variable with greater predominance of undulated surfaces, which occur in 48.62% of the basin, followed by slightly undulated relief (23.98%), strongly undulated (20.84%), mountainous (3.94%), flat (2.62%) and steep (0.05%). The areas in the basin with the most most rugged terrain contributed to the largest LS values, which ranged from 0.23 to 115. The map for this factor was the same for every year because there was no difference in steepness and length of the hills through these periods. The variation shown in the intervals of LS defined in the Figure 4 indicate that: LS < 10 occupied 38% of the area, LS 10-20 occupied 32%, LS 20 - 30 and LS occupied 13%, and LS > 30 occupied 17%.

With the classification, we proceeded to the analysis of coverage and soil management classification for the years 1984, 1990, 2000 and 2011 (Figures 5, 6, 7 and 8, respectively) and the proportion of areas in the Table 4.

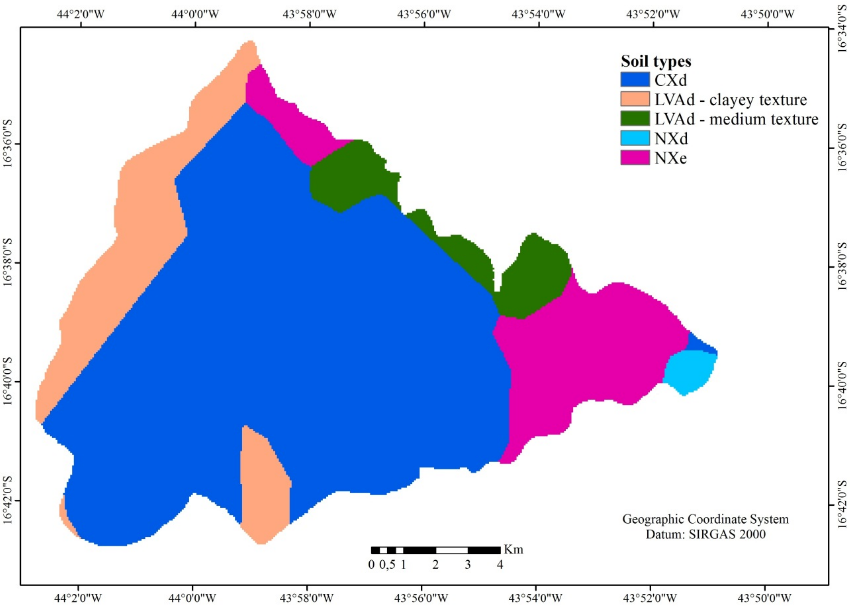

Figure 2. Map of soil classes of the Cedro river Basin/MG.
Figura 2. Mapa das classes de solo da Bacia do rio Cedro/MG.

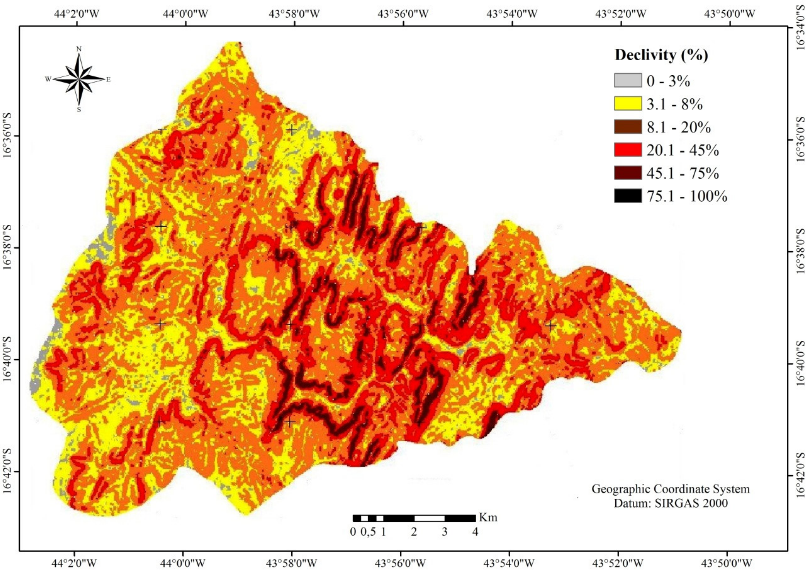

Figure 3. Maps of Declivity CLasses of the Cedro river basin, MG.
Figura 3. Mapas das Classes de Declividade da Bacia do rio Cedro/MG.

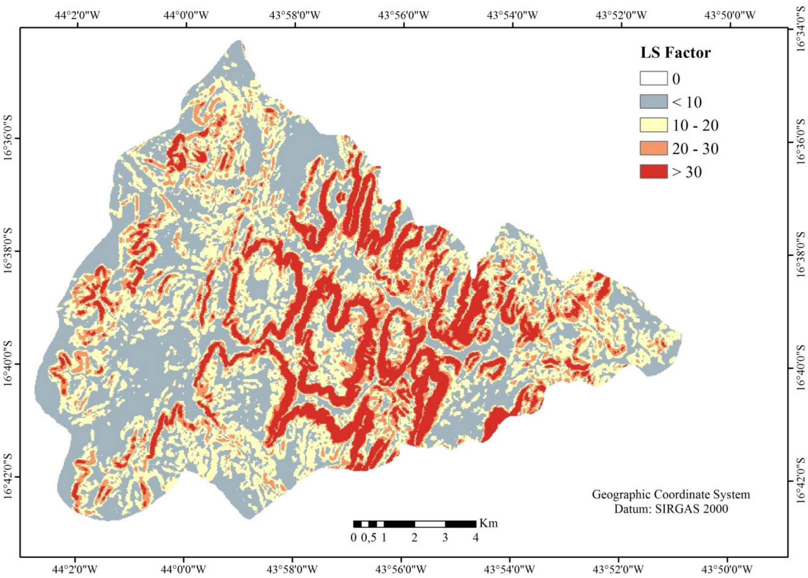

Figure 4. Map of the LS factor of the Cedro river basin, MG.
Figura 4. Mapa do fator LS da Bacia do rio Cedro/MG.

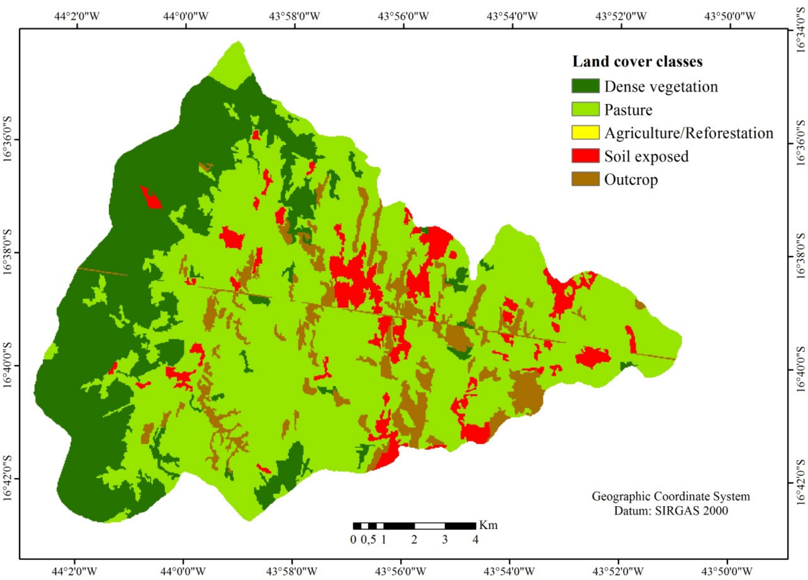

Figure 5. Map of the type of coverage and management of soil in the Cedro river basin, MG, for the year 1984.
Figura 5. Mapa do tipo de cobertura e manejo do solo existente na Bacia do rio Cedro/MG para ano de 1984.

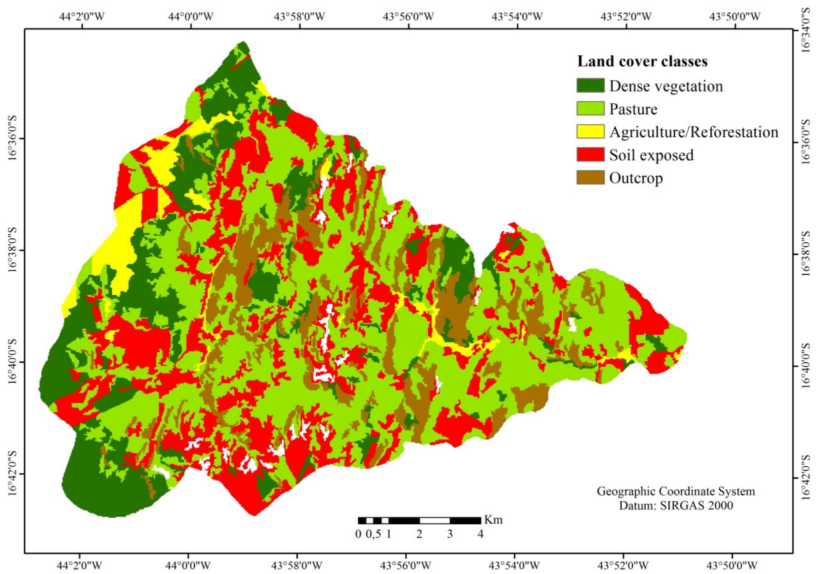

Figure 6. Map of the type of coverage and management of soil in the Cedro river basin, MG, for the year 1984.
Figura 6. Mapa do tipo de cobertura e manejo do solo existente na Bacia do rio Cedro/MG para o ano de 1990.

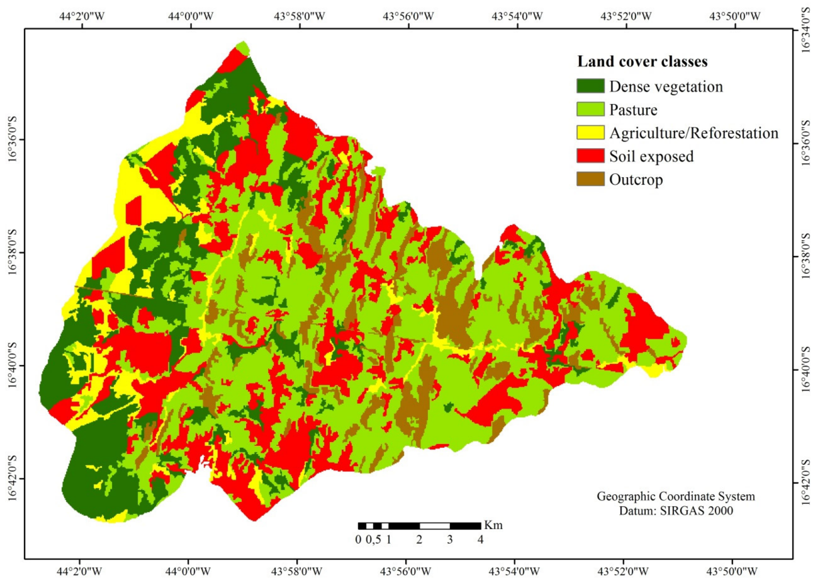

Figure 7. Map of the type of coverage and management of soil in the Cedro river basin, MG, for the year 2000.
Figura 7. Mapa do tipo de cobertura e manejo do solo existente na Bacia do rio Cedro/MG para o ano de 2000.

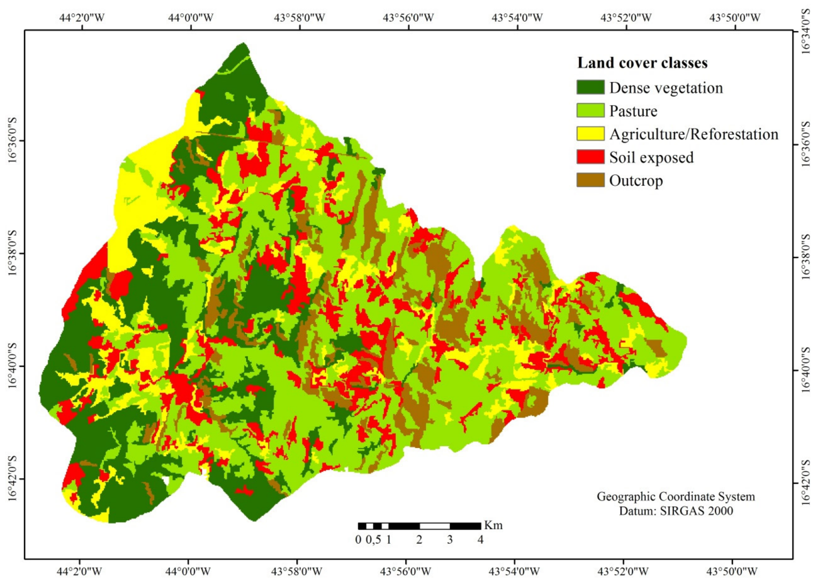

Figure 8. Map of the type of coverage and management of soil in the Cedro river basin, MG, for the year 2011.
Figura 8. Mapa do tipo de cobertura e manejo do solo existente na Bacia do rio Cedro/MG para o ano de 2011.

Table 4. Types of coverage and management of the existing soil for the periods analyzed.
Tabela 4. Tipos de cobertura e manejo do solo existente para os períodos analisados.

Year	Use and soil management (ha)				
	Dense vegetation	Pasture	Soil exposed	Agriculture/ Reforestation	Outcrop
1984	4,642.92	10,049.40	1,097.82	_	1,420.74
1990	2,827.80	7,175.39	4,157.28	746.64	2,074.32
2000	2,945.43	6,862.23	4,192.38	1,435.77	1,728.63
2011	3,859.92	6,967.35	2,447.19	2,137.41	1,776.71

Pasture areas occupied a large part of the surface of the basin in all year analyzed, in both of flat and rougher areas. As for the patterns of vegetation and knowledge of the area, most of these pastures are much degraded, what predisposes soil losses. Agricultural/forestry areas are in the surfaces of slightly undulated relief, with the exception of 1984 and in flat topographies at the river banks, because these have greater water availability, although this favors the loss by erosion, which contributes to the process of siltation.

As practices aimed at soil conservation are inexistent throughout the entire basin, the value adopted for P (conservation practices) was 1, except for agricultural/reforested areas because at some stage of the phenological cycle of plants and also depending on the type of crop, that completely covers the ground and, thus, a P factor of 0.5 can be used.

Maps of soil loss predisposition of the basin were generated (Figures 9, 10, 11 and 12) and revealed great variability of losses in its entire length. Soil predisposition intervals to erosion were

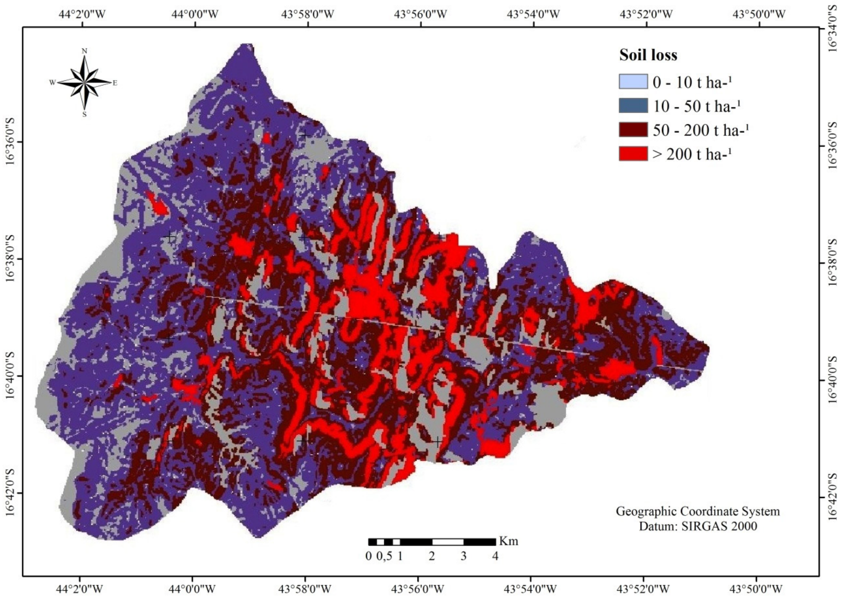

Figure 9. Map of soil loss for the year 1984 in t ha-1 year-1 of the Cedro river Basin, MG.
Figura 9. Mapa da perda de solo para o ano de 1984 em t ha-1 ano-1da Bacia do rio Cedro/MG.

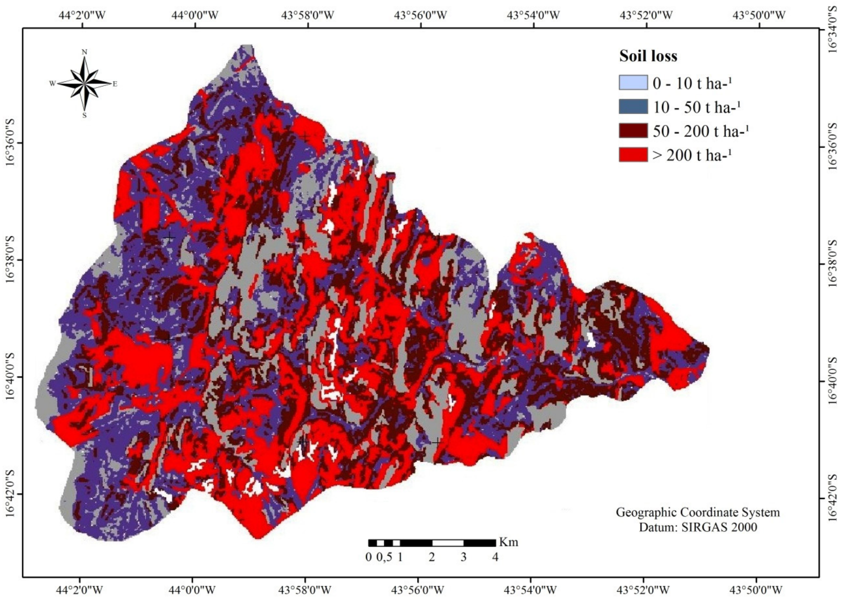

Figure 10. Map of soil loss for the year 1990 in t ha-1 year-1 of the Cedro river Basin, MG.
Figura 10. Mapa da perda de solo para o ano de 1990 em t ha-1 ano-1da Bacia do rio Cedro/MG.

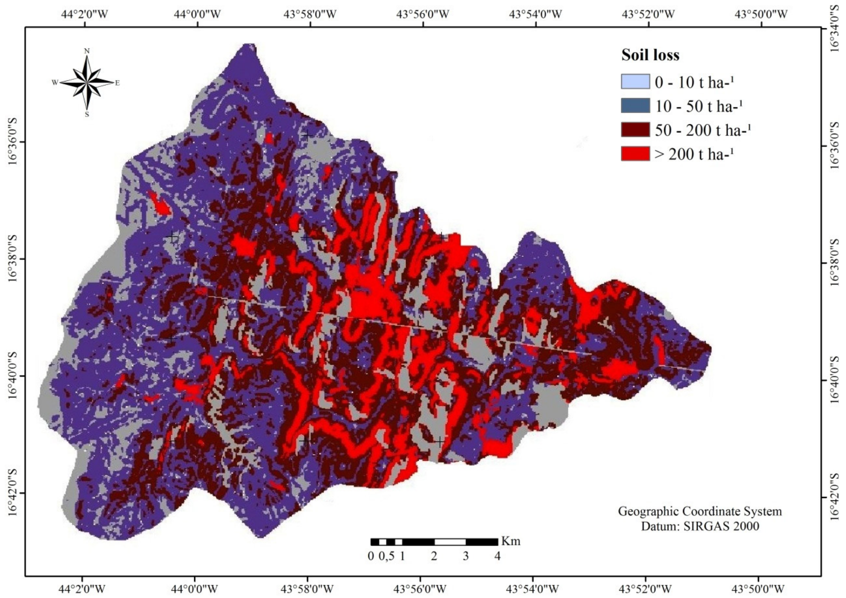

Figure 11. Map of soil loss for the year 2000 in t ha-1 year-1 of the Cedro river Basin, MG.
Figura 11. Mapa da perda de solo para o ano de 2000 em t ha-1 ano-1da Bacia do rio Cedro/MG.

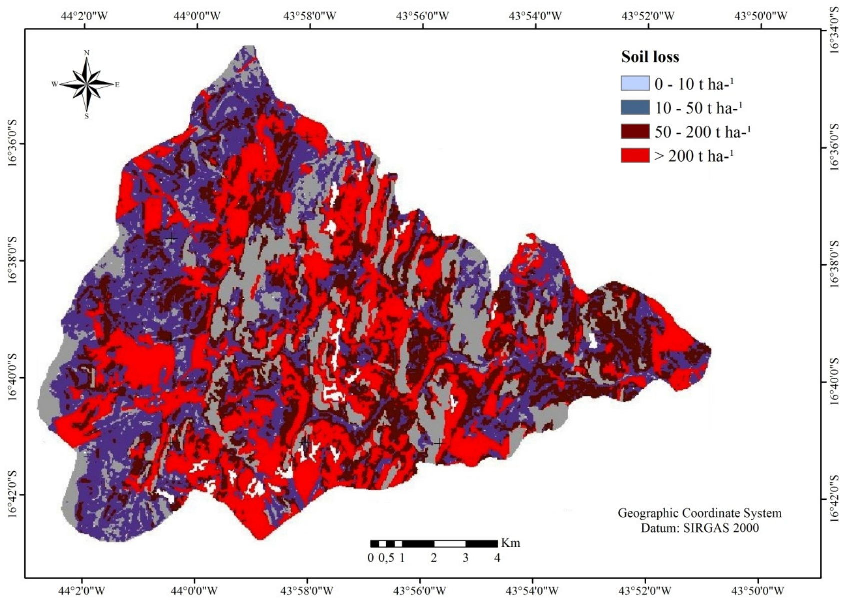

Figure 12. Map of soil loss for the year 2011 in t ha-1 year-1 of the Cedro river Basin, MG.
Figura 12. Mapa da perda de solo para o ano de 2011 em t ha-1 ano-1da Bacia do rio Cedro/MG.

prepared in accordance with the classification given by the Food and Agriculture Organization - FAO (1967). As shown in Table 5, the largest loss interval estimated for the years 1984, 1990, 2011 was 10 to 50 t ha-1 year-1, corresponding to 40.31%, 29.05% and 38.67% of the basin, respectively. This are considered moderate losses. In turn, for the year 2000, the greatest loss interval was > 200 t ha-1 year-1.

The high soil loss values for the Cedro river basin, MG, stresses the need to develop projects aimed at conservation practices for the whole contributing area. This would aid to preserve water resources and also the fertility of croplands, preventing silting and enabling the replenishment of the water table. For areas with high soil loss associated with steep slopes, a recomposition of vegetation and protection of the rivers' headwaters would be necessary. Thus, there is a need for managers to implement plans for conservation of these areas in the basin.

Table 5. Estimation of soil loss for the time series.
Tabela 5. Estimativa da perda de solo para a série temporal.

Soil loss classes ($t\ ha^{-1}\ year^{-1}$)	Area (ha)			
	1984	1990	2000	2011
0 - 10 (Low)	2,985.4	3,056.6	2,803.7	3,025.9
10 - 50 (Moderate)	6,866.1	4,885.0	4,963.1	6,581.8
50 - 200 (High)	5,009.7	4,036.8	4,241.7	4,287.8
> 200 (Very high)	2,172.5	4,840.6	4,993.8	3,122.5

4. CONCLUSIONS

The period between 1990 and 2000 consisted of larger areas with exposed soil.

Soil loss for 1984 ranged from low to moderate.

Higher soil losses were observed for the years 1990 and 2000.

The use of GIS associated with USLE represents an important tool for estimating these soil losses.

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