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Assessment of the current soil erosion in Piranga River Basin, Minas Gerais state

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Abstract: The objective of the present study was to apply the Revised Universal Soil Loss Equation (RUSLE) using GIS tools to the Piranga River Basin (PRB), Zona da Mata region, Minas Gerais state, in order to assess the current soil erosion (CSE). The maps of rainfall erosivity (R), soil erodibility (K), topographic factor (LS), and use and management of soils (CP) were developed from a geographical model adjusted for Southeastern Brazil, soil, Digital Elevation Model (DEM) and land use maps, respectively. It was observed that, in general, more than 77% of the basin presents soil losses smaller than 2.5 Mg ha^{-1} yr^{-1} being classified as "slight" current soil erosion, which mainly occurred due to the predominance of Latosols especially covered with forests. Furthermore, high soil losses rates were observed in areas with the combination of high LS values and Cambisols covered with pasture, representing 1.69% of the basin area. The use of the RUSLE model integrated to GIS showed to be an effective tool for assessing the current soil erosion in a basin's scale, providing subsidies for adopting management and conservation practices of the soil and the water in PRB.

Keywords: Soil erosion. Revised Universal Soil Loss Equation. Rainfall erosivity

Avaliação da erosão atual do solo na Bacia do Rio Piranga, em Minas Gerais

Resumo: O presente estudo teve como objetivo aplicar a Equação Universal de Perda de Solo Revisada (RUSLE), utilizando Sistema de Informação Geográfica (GIS), na bacia hidrográfica do rio Piranga (BHRP), na Zona da Mata Mineira, a fim de avaliar a erosão atual do solo (EAS). Os mapas de erosividade das chuvas (R), erodibilidade do solo (K), fator topográfico (LS) e uso e manejo dos solos (CP) foram desenvolvidos a partir de um modelo geográfico ajustado para o sudeste brasileiro, mapas de solo, Modelo Digital de Elevação (MDE) e uso do solo, respectivamente. Foi observado que, em geral, mais de 77% da bacia apresentou perdas de solo menores que 2,5 Mg ha^{-1} ano^{-1}, sendo classificada como perda de solo "ligeira", que ocorreu principalmente devido à predominância de Latossolos cobertos com florestas. Além disso, altas taxas de perdas de solo foram observadas em áreas com altos valores de LS e Cambissolos cobertos com pastagens, o que representa 1,69% da área da bacia. O uso da RUSLE integrado ao SIG mostrou ser uma ferramenta eficaz para avaliar a erosão atual do solo em grande escala, fornecendo subsídios para a adoção de práticas de manejo e conservação do solo e da água na BHRP.

Palavras-chave: Erosão do solo. Equação Universal de Perda de Solo. Erosividade das chuvas

Introduction

Soil erosion is one of the main environmental impacts that affect the state of Minas Gerais, with degradation and impoverishment of soils with reduction of surface water quality in basins. A quick and quite accurate manner to qualitatively assess the erosive potential in a particular region is given by the application of predictive soil loss models, which consider the assets and liabilities of the erosion factors.

Alatorre & Beguería (2009) stated that maps of active erosion areas allow erosion prevention efforts to be concentrated in those places where the benefit will be highest. Methods for evaluating erosion risk on catchment and regional scales (10 to 10,000 km^2) include the application of erosion models using remote sensing and geographic information (GIS) technologies.

However, in most cases erosion models have been created for use at small scales, so their extrapolation to larger scales (catchment or regional) is very complex and sometimes leads to errors (Kirkby et al.,1996; Schoorl et al., 2000; Yair & Raz-Yassif, 2004). Despite their limitations, the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) and the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) are still the most frequently used equations for estimation of soil erosion. This is mainly due to its simplicity for predicting soil erosion, in which the average annual long term soil losses is estimated with acceptable accuracy (Beskow et al., 2009).

The RUSLE is an erosion model that predicts longtime average soil loss resulting from raindrop splash and runoff from specific field slopes in specified cropping and management systems and from rangelands (Renard et al., 1997). In this regard, the topographic parameter gains a more grounded scientific connotation, physically improving the model (Zhang et al. 2013).

Originally, the estimates of the topographic parameters were obtained from field measurements, but these procedures are not practical, especially considering large areas as a watershed. For this purpose, various procedures in GIS environment have been created to model the topographic parameters in catchment scales, allowing a faster assessment and increasing the accuracy of the measurements.

Thus, the interaction between RUSLE/GIS has been widely used to assess the soil erosion in catchments all over the world, as shown by Ozsoy et al. (2008); Shiferaw (2011) Prasannakumar et al. (2012); Zhang et al. (2013), among others. The use of map algebra through GIS has been applied for this purpose and has produced good results with the application of RUSLE (İrvem et al., 2007; Ozcan et al., 2008; Pradhan et al., 2012).

Studies regarding the use of GIS to evaluate the soil erosion in Minas Gerais state have been performed. Beskow et al (2009) applied the Universal Soil Loss Equation (USLE) to predict the soil loss and the sediment delivery ratio (SDR) in Grande/Aiuruoca River Basins, upstream from the Itutinga/Camargos Hydroelectric Plant Reservoir, in the Water Resources Planning and Management Unit GD1. The authors concluded that 53% of the basin area presented and average annual soil loss less than 5 Mg ha^{-1} yr^{-1}. In addition, the authors found that the methodology was appropriate to assess the soil erosion in the region and encouraged its application in other areas for simple, reliable identification of critical areas of soil erosion in watersheds.

Oliveira et al. (2014) applied the RUSLE in order to assess the soil erosion vulnerability in the Verde River Basin, South of Minas Gerais state. The authors concluded that the soils of the Verde River Basin present a very high vulnerability to water erosion, with 58.68% of soil losses classified as “High” and “Extremely High”, considering classes that ranged from “Slight” to “Extremely High” soil loss vulnerability. Also, the authors related that the integration of RUSLE/GIS showed an efficient tool for spatial characterization of soil erosion vulnerability in the basin.

The Piranga River Basin (PRB) is a headwater of Doce River Basin, one of the most important hydrologic units in Brazil regarding socio-economics and environmental aspects. Since the headwater regions have an important role regarding water production, the aim of this work was to evaluate the current soil erosion through the integration of RUSLE/GIS using map algebra in the Piranga River Basin (PRB), Zona da Mata region of Minas Gerais state. The results of this study will allow the identification areas more susceptible to erosion in order to provide assistance for planning and management of natural resources in the basin.

Material and Methods

The Piranga River Basin (PRB) is located in Zona da Mata region of Minas Gerais state, Brazil, between the latitudes of 20º 15’ S and 21º 15’ S and the longitudes of 43º 0’ W and 44º 0’ W, with a drainage area of 4,254 km^2 and is inserted in the Water Resources Planning and Management Unit (WRPMU) DO1, which is presented in Figure 1.

The climate is classified as Cwb, which presents two well characterized seasons: mild and rainy summer and

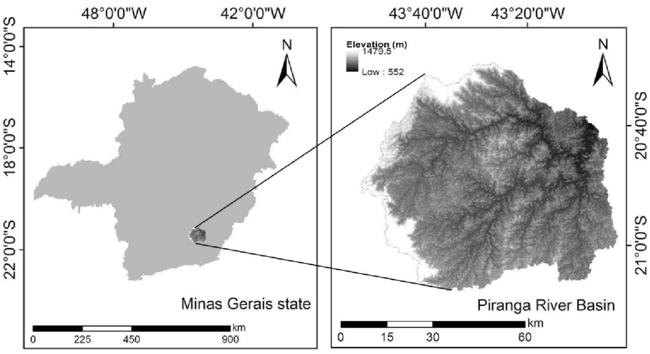

Figure 1. Location and the Digital Elevation Model (DEM) of the PRB in the Minas Gerais state

cool and dry winter, with average annual precipitation about 1500 mm. The rainfall regime is characterized by two distinct periods: the rainy season which extends from October to March, with the highest rates in December; and the dry season that extends from April to September, with the most critical drought from June to August (Water Management Institute of Minas Gerais State - IGAM, 2010).

According to the Water Resources Integrated Planning and Management of Doce River Basin (Water Management Institute of Minas Gerais State - IGAM, 2010), regarding erosion susceptibility, the PRB presents an average susceptibility to erosion considering the soil type, geomorphology and precipitation as conditioning factors to erosion occurrence, predominating the sheet, rill and gully types of erosion.

Revised Universal Soil Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) was used in this study to estimate the average annual soil loss in the PRB through a GIS environment using map algebra. The RUSLE has the following structure:

$$A = R \times K \times LS \times C \times P \tag{1}$$

where:

A – soil loss (t ha^{-1} yr^{-1});
R – rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1});
K – soil erodibility (t h MJ^{-1} mm^{-1});
LS – topographic factor (dimensionless);
C – soil use and management factor (dimensionless);
P – soil conservation practice factor (dimensionless).

Rainfall Erosivity (R)

The rainfall erosivity represents the potential of rain to cause erosion in an exposed and unprotected soil surface, which the physical definition is the product of rainfall kinetic energy and the maximum rainfall intensity in 30-minute consecutive (EI_{30}) (Wischmeier & Smith, 1978). Due to lack of detailed rainfall records, many authors correlate the EI_{30} with the Modified Fournier Index (MFI), which the rainfall erosivity value can be obtained based on monthly and annual precipitation data sets (Renard & Freimund, 1994).

In this study, for obtaining the rainfall erosivity map we applied the multivariate geographical model proposed by Mello et al. (2013), which estimates the mean annual rainfall erosivity based on the latitude, longitude and altitude of each cell of the basin, characterizing the R factor in a distributed manner. For this purpose, a digital elevation model is required. The model for estimating the mean annual R value for Southeastern Brazil is given by:

$$\begin{aligned} R \;=\; & -399433 + 420.49 \times A - 78296 \times LA - 0.01784 \times A^2 - \\ - \;& 1594.04 \times LA^2 + 195.84 \times LO^2 + 17.77 \times LO \times A - \\ - \;& 1716.27 \times LA \times LO + 0.1851 \times LO^2 \times A + 0.00001002 \times \\ \times \;& LO \times A^2 + 1.389 \times LO^2 \times LA^2 + 0.01364 \times LA^2 \times LO^3 \end{aligned} \tag{2}$$

Where R is the average annual erosivity (MJ mm ha^{-1} yr^{-1}), A is the altitude (m), LA latitude and LO longitude, both in negative decimal degrees.

Soil erodibility (K)

The soil erodibility is the intrinsic susceptibility of the soil to erosion, which is influenced by soil properties that affect the infiltration rate, permeability, total water capacity, dispersion, splashing, abrasion and transporting forces of the rainfall and runoff, such as: percentage of silt and sand; structure; organic matter; parental material and others (Ozsoy et al., 2012; Wischmeier & Smith, 1965). The erodibility factor (K) is represented by the relationship between the soil loss and the rainfall erosivity, when such data are derived individually for each rainfall event (Mannigel et al., 2002).

According to the established norms of the USLE (Wischmeier & Smith, 1965), the K-factor is obtained through time-consuming and high-costs experiments, which considers the physical behavior of the erosion process. Due to these reasons, indirect approaches to estimate the soil erodibility factor were created in order to facilitate its obtaining, such as soil erodibility models and nomographs, wich take into account the soil properties as texture, permeability, structure and others.

In this work the soil classes were merged into soil types, since the difference between the values of the erodibility among classes is minimal. The K values for each soil applied in this study were extracted from the literature as this factor has been well studied and documented in Brazil. The soil types Cambisol and Oxisol were obtained from indirect measurements while Argisol was obtained from direct measurement (soil loss plots). The K values are presented in Table 1.

The soil map, presented in Figure 2, developed by Minas Gerais State Environmental Foundation (FEAM, 2010) was used to obtain the K-factor map.

Table 1. Soil erodibility values and their respective authors

Soil type	K ($t\ h\ MJ^{-1}\ mm^{-1}$)	Authors
Argisol	0.033	Sá et al. (2004)
Cambisol	0.0508	Araújo et al. (2011)
Oxisol (Latosol)	0.01913	Mannigel et al. (2002)

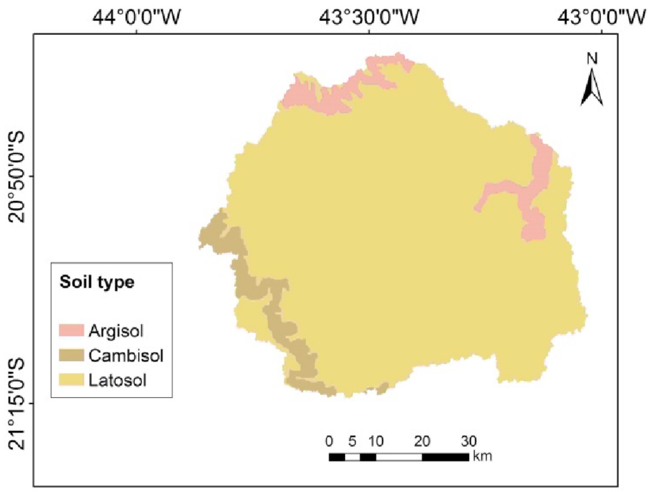

Figure 2. Soil type map from Piranga River Basin (PRB)

Topographic factor (LS)

The LS-factor is used in the USLE family to consider the effect of topography on erosion. The topographic factor depends on the slope steepness and slope length factor (LS), and it is an essential parameter to quantify the erosion generated due to the influence on surface runoff speed (Silva et al., 2012).

According to Nisar et al. (2000), the effect of slope and its gradient in the intensity of the erosive process (LS-factor) can be determined in GIS environment applying the digital elevation model combined with algorithms for obtaining the distributed maps of the length and steepness.

The topographic factor, originally known as LS (Wischmeier & Smith, 1965; Wischmeier & Smith, 1978), adapted to RUSLE, can be estimated through Equation 3, proposed by Engel, 2003:

$$LS = \left[\frac{(\text{Flow accumulation})\cdot(\text{Cell size})}{22.13}\right]^{0.4}\left\{\frac{\left[\sin(\text{Slope})\right]}{0.0896}\right\}^{1.3} \quad (3)$$

In which the accumulated flow and slope map were derived from the Aster digital elevation model (DEM) with a resolution of 30 m.

The slope map is presented in Figure 3.

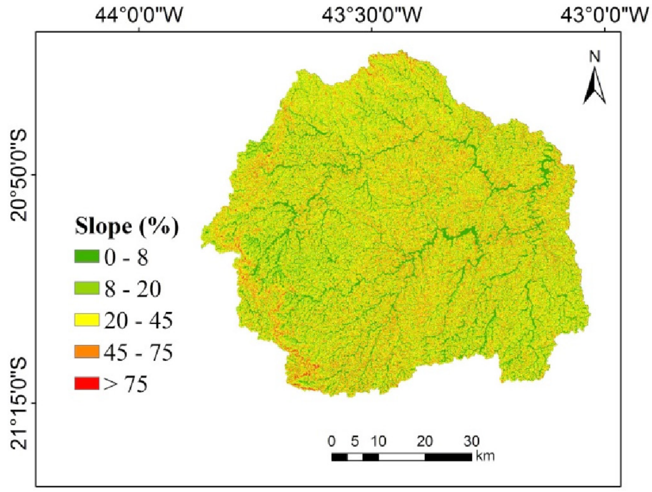

Figure 3. Slope map of the Piranga River Basin

Soil use and management factor (CP)

This factor varies according to vegetation cover (land use), ranging from 0 to 1, where higher values represent greater disaggregation of soils to rainfall impact and surface runoff. This factor is extremely important regarding soil erosion since the vegetation cover can be changed throughout a period of time.

The values of C used in this study were obtained from the literature and are shown in Table 2. The factors "Bare Soil", "Urbanization" and "Water" were considered, respectively 1, 0 and 0.

The land use map was derived from Landsat 8 images and classified by the maximum likelihood method, as shown in Figure 4.

According to Wischmeier & Smith (1978), the P-factor in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope culture. Improved tillage practices, sod-based rotations, fertility treatments, and greater quantities of crop residues left on the field contribute materially to erosion control.

Table 2. Soil use and management values (C) applied to the study

Land use	C	Author
Agriculture	0.29	Beskow et al. (2009)
Pasture	0.09	Ozsoy et al. (2012)
Forest	0.01	Beskow et al. (2009)
Eucalyptus	0.3	Martins et al. (2010)
Water	0	
Urbanization	0	
Bare soil	1	

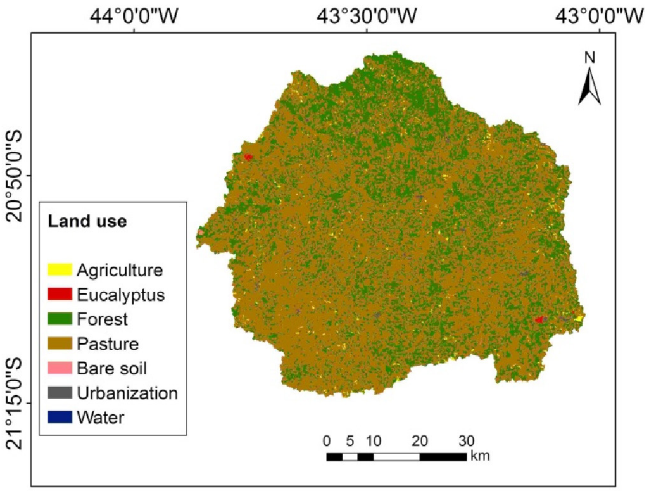

Figure 4. Land use map of the Piranga River Basin

In other words, the P factor expresses how the surface and management practices are used to reduce erosion. Since the identification of soil management and soil conservation practices are difficult to identify from satellite images and also for representing a very small percentage of the basin area, the P factor was considered to be equal to 1. This methodology has been applied in several studies such as Pradhan et al. (2011), Vemu & Pinnamaneni (2011), Silva et al. (2012) and Oliveira et al. (2014).

Results and Discussion

It was observed that the mean annual rainfall erosivity map (R-factor) in the PRB showed values ranging from 7233 to7900 MJ mm ha^{-1} yr^{-1} with greater values located in both low latitudes and longitudes. According to the classification proposed by Foster et al (1981), the rainfall erosivity in most of the PRB is classified as “high erosivity” (7,357 to 9,810 MJ mm h^{-1} ha^{-1} yr^{-1}). These rainfall erosivity values fall within those found by Mello et al. (2007) and Mello et al. (2013) for Zona da Mata region, in Minas Gerais state. The R-factor map is presented in Figure 5.

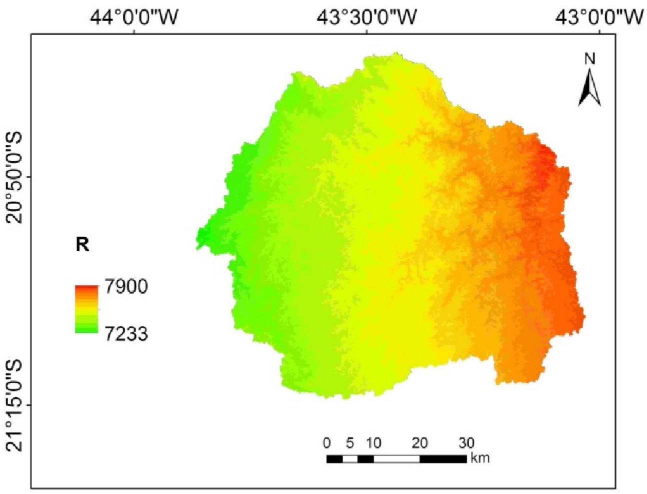

Figure 5. Rainfall erosivity (R) map of the Piranga River Basin

The results associated with the LS factor showed that their values vary from 0 to 13.81 in PRB. We can observe that higher LS values are distributed in higher altitudes and consequently lower values are presented in lower altitudes. These results are based on the methodology proposed by Moore & Burch (1986) which consists in incorporating unit stream power theory, whereby the water present on the soil surface has energy capable of disaggregate and transport soil particles when they move downstream.

Also, these results indicate that the topography of the basin allows the occurrence of low values of soil erosion, where high soil loss rates will only occur in a small part of the basin with steeper slopes, which increase significantly the surface runoff speed.

The values of the factors K and CP are only represented by the spatial distribution of the soil and land use maps, respectively. In one hand, it is noted that the Latosols occupy 89% of the basin area, which shows that the PRB has low natural vulnerability to erosion regarding soils, since the Latosols has the lowest K-factor value. On the other hand, the land use map showed that there is a predominance of extensive pastures, wich has high value of CP, presenting high susceptibility to soil erosion concerning vegetation cover. The maps of the factors LS, K and CP are shown in Figure 6.

The spatial distribution of the current soil erosion is presented in Figure 4, adapting the classification proposed by Beskow et al. (2009), which allows a qualitative classification of the current soil erosion into classes ranging from "Slight" to "Extremely High".

This type of classification of the potential soil loss associated with GIS allows to analyze the degree of impact that a particular activity may result in the behavior of soil erosion process in the basin, resulting, mainly for agricultural areas, loss of arable land and nutrients, siltation of water bodies, among other problems, and thus, the characterization of the most sensitive areas contributes as an important management tool, guiding land use and its possible impacts (Durães, 2013).

In general, the predominant classes of current soil erosion in the PRB were “slight” and “slight to moderate”, which represented 77.94% and 9.55% of the soil loss, respectively (Table 3). These results can be explained by the interaction between the soil type and the land use in the basin.

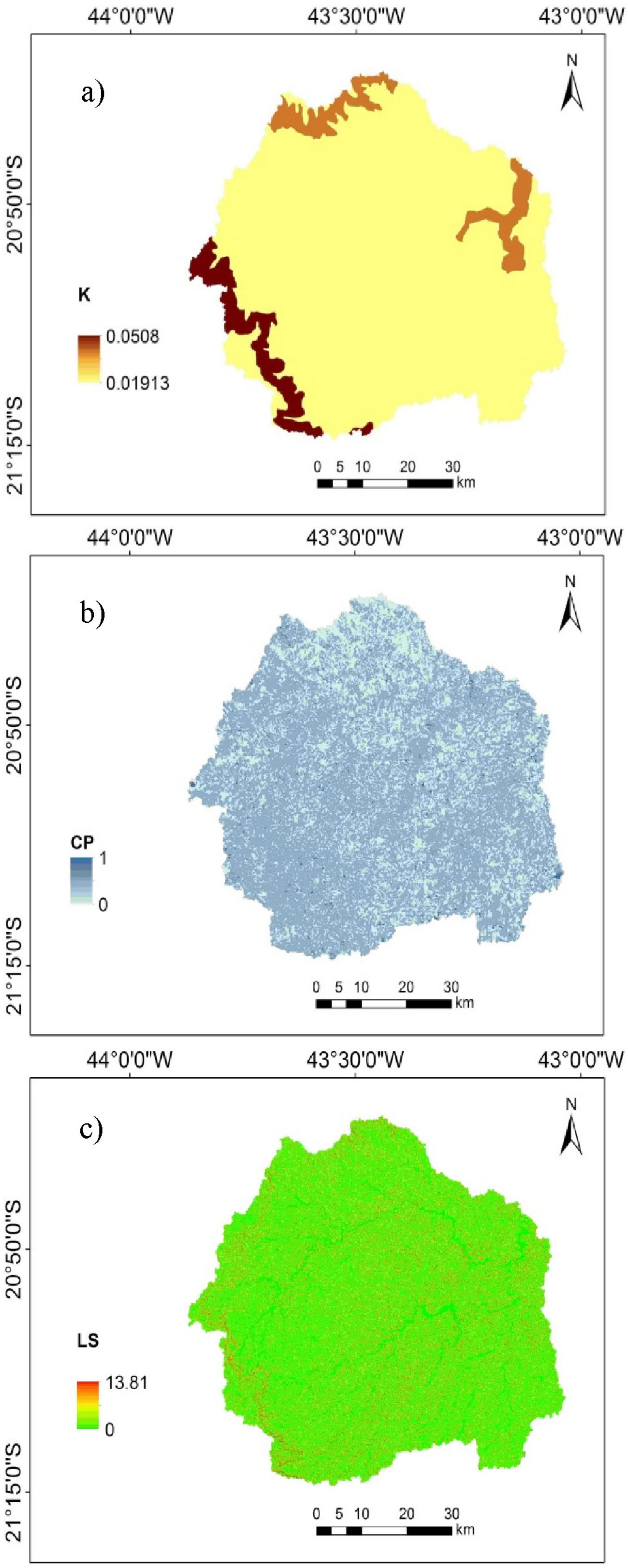

Figure 6. Maps of the factors K (a), CP (b) and LS (c)

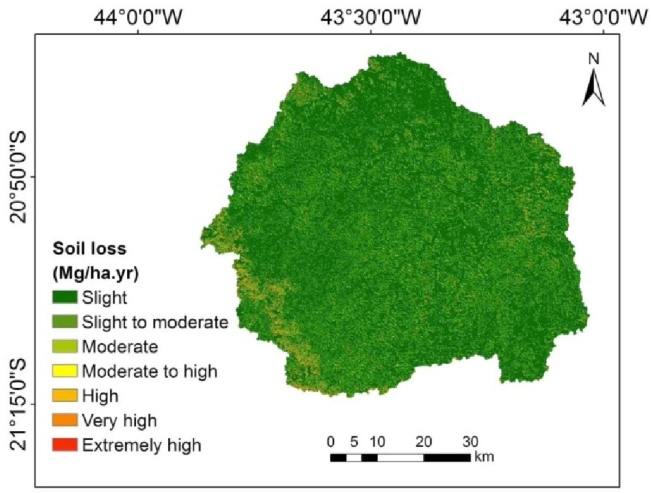

Figure 7. Spatial distribution of the current soil erosion in PRB

Table 3. Classification of the current soil erosion adapted from Beskow et al. (2009) and its percentage distribution in PRB

Soil loss (Mg ha^{-1} ano^{-1})	Current soil erosion	Area (%)
0 - 2.5	Slight	77.94
2.5 - 5	Slight to Moderate	9.55
5 - 10	Moderate	8.46
10 a 15	Moderate to High	2.36
15 - 25	High	1.15
25 - 100	Very High	0.53
> 100	Extremely High	0.01

Latosols in PRB represent almost 90% of the area and since this type of soil have low susceptibility to soil erosion (i.e. low soil erodibility), it was expected that low values of soil loss would occur in these areas, especially those covered with forest (33% of the area), which has high efficiency in protecting the soil against the active erosion agent (rainfall) (Oliveira et al., 2014).

On the other hand, high soil loss values was observed in areas with presence of Cambisols covered with extensive pasture, located in steeper slopes in the Southwest part of the basin, but only represented 1.69% of the soil loss in the PRB. These findings are corroborating with Oliveira et al. (2014), which related high soil losses due to presence of Cambisol covered with pastures in steep slopes. Similar results regarding high soil loss rate in Cambisols can be found in Beskow et al. (2009).

Also, the results showed that although there is predominance of 65% of the area of extensive pasture (i.e. high CP-factor value) the PRB presented low soil loss values, mainly due to the presence of Latosols in these areas.

Conclusion

The use of RUSLE/GIS showed to be an appropriate tool for assessing the current soil erosion in Piranga River Basin and facilitating sustainable land management through conservation planning. In general terms, the PRB can be classified as "slight" current soil erosion, which represents 77.94% of the basin area. Only 1.69% of the PRB area presented high soil loss rates, which occurred in areas with the combination of Cambisols covered by pastures. With these findings, we were able to conclude that the Piranga River Basin has low vulnerability to soil erosion, but it does not relieve the adoption of conservation practices and soil and water management in the area.

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