CLASSIFICATION OF PASTURE DEGRADATION LEVELS IN TERMS OF HYDRIC EROSION RISK IN QUARTZIPSAMMENTS AREAS AT ALTO TAQUARI WATERSHED (MS/MT, BRAZIL)

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Abstract

Pasture degradation is currently one of Brazil's agriculture main problems. Pasture areas grown on Quartzipsamments (RQ) at the Alto Taquari watershed (BAT) are important sources of sediments which intensify the Taquari river's siltation in Pantanal. The objective of this work was to assess the use of the Linear Spectral Mixture Model (LSMM) in the mapping and characterization of the current degradation level of pastures planted on RQ at BAT in terms of erosion risk. Using Landsat 5 satellite images of 2010 and employing the LSMM, we generated an image for exposed soil (ES), which was used along with field work to define three pasture degradation levels: low degradation level or not degraded (ES ≤ 20%), medium degradation level (20% < ES ≥ 45%) and high degradation level (ES > 45%). In 2010, the pastures grown on RQ at BAT encompassed a total of 851,204 ha, which corresponded to 66.3% of this soil class and to 30.1% of the watershed surface. The largest amount of pasture areas, around 57%, showed medium degradation level, about 9% showed high degradation level, and the remainder, around 34%, were pastures with low degradation level or not degraded.

Key words: Geotechnology. Linear Spectral Mixture Model. Cerrado Biome. Alto Paraguai watershed. Degraded pasture recovery.

Resumo

Classificação de níveis de degradação de pastagens quanto ao risco de erosão hídrica em áreas de neossolos quartzarênicos da bacia do Alto Taquari (MS/MT)

A degradação das pastagens é um dos maiores problemas da agropecuária do Brasil na atualidade. Áreas de pastagens cultivadas em Neossolos Quartzarênicos (RQ) na bacia do alto Taquari (BAT) constituem importante fonte de sedimentos, que intensificam o assoreamento do rio Taquari no Pantanal. O objetivo do trabalho foi avaliar o Modelo Linear de Mistura Espectral (MLME) no mapeamento e caracterização atual de níveis de degradação das pastagens cultivadas em RQ na BAT quanto ao risco de erosão. Utilizando imagens do satélite Landsat 5 do ano de 2010 e empregando o MLME foi gerada imagem para solo exposto (SE), o qual, apoiado por trabalho de campo, foram definidos três níveis de degradação das pastagens: pastagens com baixo nível de degradação ou não degradadas (SE ≤ 20%), pastagens com nível de degradação médio (20% < SE ≥ 45%) e alto (SE > 45%). As pastagens cultivadas em RQ na BAT em 2010 totalizavam 851.204 hectares, correspondendo a 66,3% dessa classe de solo e a 30,1% da superfície da bacia. A maior parte das áreas de pastagens em RQ foi caracterizada como sendo de médio nível de degradação, cerca de 57%. Nível de degradação alto correspondeu a aproximadamente a 9% e o restante, cerca de 34%, como pastagens sem degradação ou baixo nível de degradação.

Palavras-chave: Geotecnologia. Modelo Linear de Mistura Espectral. Bioma Cerrado. Bacia hidrográfica do alto Paraguai. Recuperação de pastagens degradadas.

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INTRODUCTION

One of the main causes of environmental and socioeconomic impacts in the Brazilian Pantanal is the intensification of erosion processes at plateau areas where Pantanal rivers spring. The most notable example is the siltation of the Taquari river. The main cause of this siltation was the disorderly agricultural expansion at the Alto Taquari watershed (BAT) after 1970 (GALDINO; VIEIRA, 2005).

The predominant use of BAT lands is for rearing beef cattle. The last survey of the watershed whole surface was performed in 2000, and shows that pastures, formed mainly by *Brachiaria* forage, covered about 1.5 million hectares, which corresponded to 55% of the BAT's surface (SILVA; SANTOS, 2011). Of this total, approximately 740 thousand hectares, equivalent to 48% of these pastures, were planted on sandy soils classified as Quartzipsamments. Thus, the pastures grown on BAT's Quartzipsamments corresponded to 26.4% of the watershed surface in 2000 (SILVA; SANTOS, 2011). According to the Conservation Plan for the Alto Taquari Watershed (*Plano de Conservação da Bacia do Alto Paraguai*, SANTOS et al., 1997) these soils were named "Quartzy Sands" in the old soil classification made by Embrapa (1988), and were later reclassified as Quartzipsamments (RQ), according to the Brazilian Soil Classification System – SiBCS (EMBRAPA, 2006). The RQ extends along an area of approximately 13 million hectares at the BAT, i.e. it occupies almost half (46.1%) of the whole watershed surface (SANTOS et al., 1997). Other important soil classes at the BAT, according to Santos et al. (1997), are the Red-Yellow Podzols (PV), Dark-Red Latosols (Oxisol) (LE) and Lithic Psamments (R), which occupy 19.8%, 14.8% and 13.3% of the watershed surface respectively.

Due to its high content of sand and its low fertility, RQ is not commonly used for annual crops and fruit crops. This soil is almost exclusively covered by two vegetation classes, woodlands/savanna (*cerrado*, trees) or pastures (GALDINO, 2012).

The areas occupied by pastures are the ones with the highest rate of accelerated soil erosion at the watershed, partly due to inadequate or deficient management of the soil, which, due to its sandy texture and natural low fertility, renders low water retention capacity and nutrient deficiency, culminating in deficient biomass production and soil exposure. Indiscriminate deforesting of hillsides and mountain tops are other factors that render accelerated erosion at the study area (BRASIL, 1982). The immediate consequence of the greater exposure of the soil to the action of erosive agents, especially rain, is the intensification of hydric erosion. Thus, areas covered by pastures on RQ constitute important sources of soil losses and production of sediments, which reach the BAT's water streams and intensify the Taquari river silting process.

Several authors indicate pasture degradation as one of the main problems currently faced by the Brazilian cattle production (MACEDO et al., 2000; VILELA et al., 2001). Macedo et al. (2000) estimated that 80% of the 50 to 60 million hectares of planted pastures in the central region of Brazil, which is responsible for 55% of the national meat production, show some degree of degradation. Pasture degradation jeopardizes the sustainability of animal production, and may be explained as a dynamic process of degeneration or decrease in relative productivity (MACEDO, 2000). Among the most important factors related to pasture degradation are the inadequate animal management and the lack of nutrient replenishment. Excessive animal allotment with no adjustments for adequate bearing capacity, and lack of maintenance fertilization have been accelerators of the degradation process (MACEDO, 2000).

To minimize erosion, the correct management of pasture areas and the adoption of conservationist practices are essential. Data from the Agricultural Census of 1995 (IBGE, 1998) show that only 30% of the rural properties used fertilization techniques, chemical or organic, and soil correction. Investments in soil conservation practices were made in only

14.5% of the properties; 10.6% of the farms used contour cultivation; and terracing was adopted in only 3.4% of the rural properties (IBGE, 1998).

In the description of pasture degradation phases proposed by Spain and Gualdrón (1988) and Macedo (2000) the incidence of accelerated soil erosion appears as the most critical degradation phase. Practice shows that accelerated erosion is found in all phases, and tends to increase with the decrease of soil cover, by pasture as well as by invasive plants and by residues above the soil surface (GALDINO, 2012).

The recovery of degraded pastures is currently one of the Brazilian federal government priorities. The Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) created a program for the reduction of greenhouse gas emissions in agriculture, known as the ABC Program, which foresees the funding of projects for the recovery of degraded pastures (the "ABC Recovery") by the Brazilian Development Bank (BNDES, 2012)

While assessing the effects of the use and management of pastures planted on BAT's Quartzipsamments, Galdino and Marinho (2012) verified that less soil cover by plants (pasture and invasive plants) decreased the percentage of canopy and residues above the soil surface, decreased the root density, and consequently favored the increase of erosion rates.

Geotechnologies, including geographic information systems and digital processing of remote-sensing images, are essential tools for the synoptic analysis of targets and the spatialization of phenomena or natural and anthropic patterns which define rural landscapes. Particularly in the interpretation of orbital-sensing images, the method known as Linear Spectral Mixture Model (LSMM) estimates the reflectance proportions of different components which contribute to the total reflectance formation within the sensor's resolution element, or "pixel" (SHIMABUKURO; SMITH,1991). Examples of LSMM applications are the works developed by Asis and Omasa (2007), who used fraction GV, NPV and Soil images to estimate soil use and management factor using the Revised Universal Soil Loss Equation (RUSLE's C factor), and by Galdino (2012), who used the exposed soil abundance image (Soil) as an indicator of pasture degradation levels produced by erosion.

OBJECTIVE

This work aims to assess the Linear Spectral Mixture Model potential for use in the mapping and characterizing of different degradation levels in pastures planted on BAT's Quartzipsamments in terms of hydric erosion.

MATERIALS AND METHODS

Study Area

The focus of this study was planted pasture areas on Quartzipsamments at the Alto Taquari watershed (BAT) in the year 2010. This soil class was extracted from the soil map of the *Plano de Conservação da Bacia do Alto Paraguai* – PCBAP (SANTOS et al., 1997).

The BAT has an area of approximately 28,000 km^2. Over 86% of its surface is located in the Mato Grosso do Sul state, and aproximately 14% is located in the Mato Grosso state (GALDINO; VIEIRA, 2005). The BAT is part of the plateaus of the Alto Paraguai watershed

(BAP), on the west portion of the Brazilian Pantanal, located between 19º39’20”S and 17º14’20’’S and 55º02’47”W and 53º08’35’’W (Figure 1).

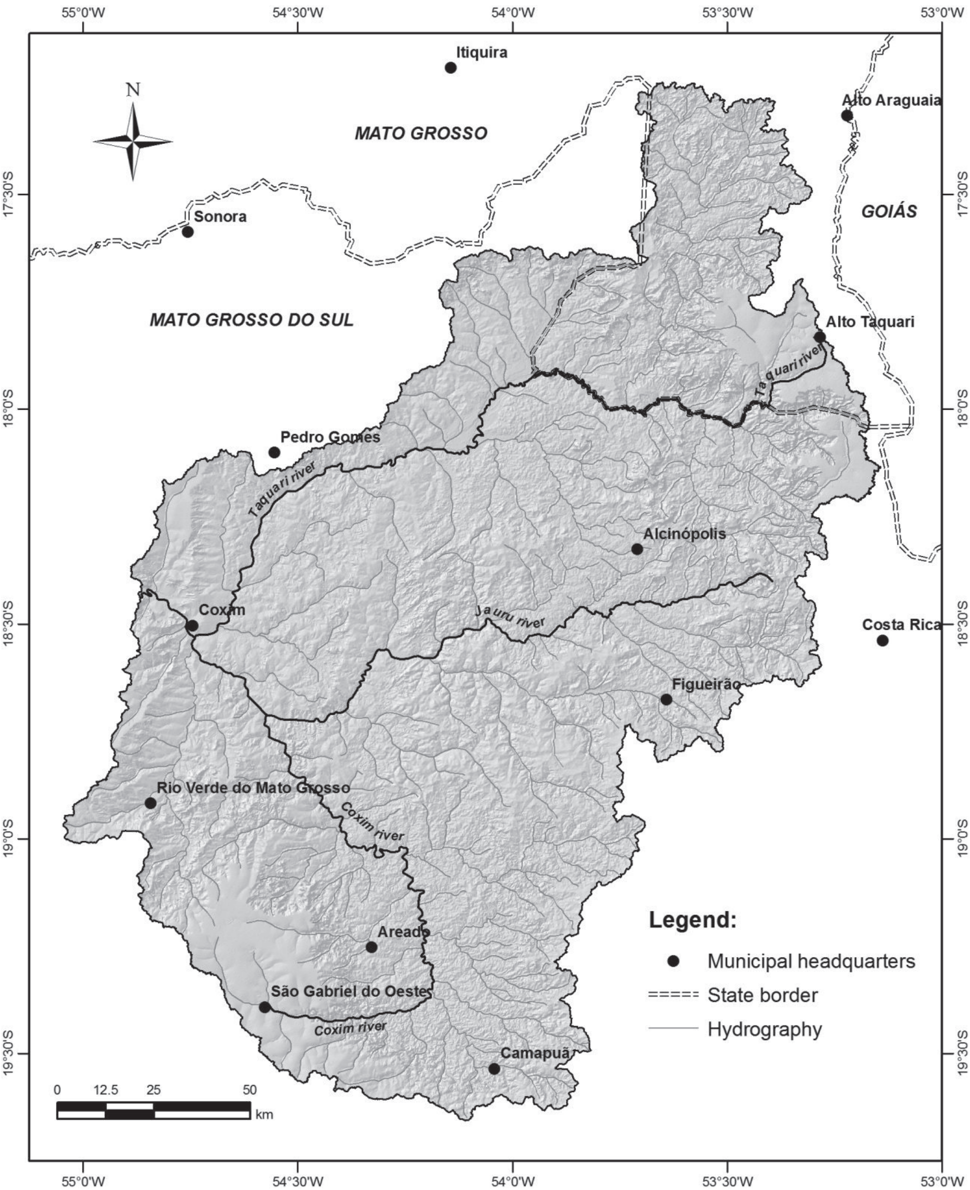

Figure 1 - Alto Taquari watershed (BAT): hydrography, municipal headquarters, and state border

BAT's climate is Aw according to the Köppen classification (SILVA; SANTOS, 2011), with average annual rainfall of 1,440 mm, and over 80% of the rainfall concentrated from October to March (GALDINO; MARINHO, 2011).

The main tributary of the Taquari river is the Coxim river, in addition to the Jauru river which is also important for the BAT (Figure 1).

In 2000, the lands at the BAT were used mainly for planted pastures, which covered around 55% of the watershed (SILVA; SANTOS, 2011). Annual crops, especially soybean and maize, occupied approximately 336,000 ha or about 12% of the BAT's lands. *Cerrado* (savanna) and *Mata* (woodlands) were the main natural vegetation classes, and covered 17.41% (487,500 ha) and 11.68% (327,000 ha) of the watershed surface respectively (SILVA; SANTOS, 2011).

The topography comprises plateaus and residual plateaus always surrounded by escarpments, and sometimes shaping *cuesta* fronts dissimulated by erosive activities and depressions (SILVA; SANTOS, 2011). The average height is 449 m, varying between 177 and 920 m. The predominant declivity class is of mild slopes, which occupy almost half of the total BAT's area, with a declivity between 3 and 8%. The slope class (declivities between 8 and 20%) occurs in 22% of the BAT's area, where there is a greater risk of soil erosion. Declivities beyond 20%, which render high erosion risk in susceptible soils, cover about 5% of the watershed surface (GALDINO; WEILL, 2010).

Pasture mapping on BAT's Quartzipsamments in 2010

Landsat 5 TM images, soil class shapes of the watershed and land use shapes of the BAT-MS from the year 2007 were used in the updated mapping (2010) of planted pasture areas in BAT's RQ.

For the identification of RQ areas at the BAT, we used vectorial information (shapefile) on a 1:250,000 scale produced by PCBAP (SANTOS et al., 1997) on the soil classes. Although they were obtained from an exploratory survey, this information is currently the most detailed data available for the BAT.

In order to generate the reflectance images necessary for the mapping of RQ's pasture areas, we initially obtained Landsat 5 TM images of the year 2010, made available by the Brazilian National Institute For Space Research (INPE) at http://www.dgi.inpe.br/CDSR/. The Landsat 5 TM images used were: 224/72, 224/73 and 224/74, from April 21; 225/72, from May 14; 225/73, from April 12 and 28; 225/74, from April 12. For all images, we obtained bands 1 (0.452 - 0.518 μm), 2 (0.528 - 0.609 μm), 3 (0.626 - 0.693 μm), 4 (0.776 - 0.904 μm), 5 (1.567 - 1.784 μm) and 7 (2.097 -2.349 μm).

To register the six bands (1, 2, 3, 4, 5 and 7) of each of the scenes, we initially generated images in the R5-G4-B3 color composition. Then, we registered these images based on the GeoCover 2000 mosaic by means of first-degree polynomial transformations and interpolation using the nearest neighbor method, using the *Georeferencing* extension of the ESRI ArcGIS 9.3 software. Based on the control points obtained during the image registering, we registered the bands.

For the atmospheric correction, we used the DOS (Dark Object Subtraction) method proposed by Chavez (1988; 1989). DOS is a method for the correction of atmospheric scattering in which the atmospheric interference is estimated directly from the satellite images digital numbers (ND) and the atmospheric absorption is ignored. This technique does not require the obtention of data on the atmospheric conditions on the day the images were obtained. To perform the atmospheric correction using the DOS method along with the conversion of ND to reflectance we used the electronic spreadsheet created by Gurtler et al. (2005), in which the data related to minimum (L_{min}) and maximum (L_{max}) radiance and to the TM sensor's irradiance (E) were updated according to Chander et al. (2009).

To calculate the atmospheric scattering we used band TM1 as the reference band. The data entered into the spreadsheet were band 1's histogram, the type of sensor (TM), the image date and the solar elevation angle. Then, to obtain the reflectance images for the bands, we used the *Raster Calculation* tool of ESRI's ArcGIS 9.3 software's *Spatial Analyst* extension.

To obtain the mosaic of the image reflectance in each of the six Landsat 5 TM bands for the study area, we initially converted the UTM projection to geographic coordinates (datum WGS84).

To map the planted pasture areas on RQ at the BAT we used Landsat TM images from 2010 in the R5-G4-B3 color composition, the map of RQ at the BAT, and the land-use survey performed in 2007 for the BAT-MS made available in vectorial form (shape) by Silva et al. (2011). The visual interpretation of this information was used to update the map of pasture areas on RQ at the BAT for 2010. The whole area comprised 851,204 ha, which corresponded to 66.3% of the RQ areas at the BAT and to 30.1% of the watershed surface.

Pasture degradation level mapping on BAT's Quartzipsamments

To classify the different degradation levels of the pastures planted on RQ at the BAT in 2010 we considered the soil loss ratio (SLR) values and the soil use and management factor (C factor) of the Revised Universal Soil Loss Equation – RUSLE (RENARD, et al., 1997), obtained from field surveys made at two times of the year in nine pastures (plots) by Galdino (2012). Based on the statistical analysis of these values supported by literature data, we regrouped the plots according to pasture degradation level similarity in terms of the RUSLE's C factor.

Exposed soil was the parameter that showed greater correlation to soil use and management factor, i.e. to pasture degradation level in terms of hydric erosion risk. Regrouping the plots with similar levels of the C factor – and consequently of exposed soil – enabled differentiating three pasture degradation classes in terms of erosion risk: pastures not degraded and/or with low degradation level (exposed soil $\leq$ 20%); pastures with medium degradation level (20 < exposed soil $\geq$ 45%); and pastures with high degradation level (exposed soil > 45%) (GALDINO et al., 2012).

The Linear Spectral Mixture Model (LSMM) was used to generate the abundance image of exposed soil (ES) in planted pasture areas on RQ at the BAT. In an agricultural area, for example, the model usually decomposes the reflectance contained in a given "pixel" in four components – green vegetation - GV; non-photosynthetic vegetation - NPV; soil; and shadow/water. Although the LSMM is not considered an image classification method, for its main purpose is not obtaining theme classes, its application enables obtaining something similar to a "mild classification", i.e. the pixel may show multiple identifiers. For each component analyzed using LSMM, the lighter and darker areas in the image respectively indicate a stronger or less strong proportion of the target. In the product obtained, referred to as fraction image or abundance image, the variation in grayscale indicates, as a continuum, the proportion of a given target (SHIMABUKURO; SMITH, 1991).

To generate the raster file of the pasture degradation classes, we used ArcGIS's software Raster Calculator tool, the abundance image, and the limits for exposed soil.

To obtain the abundance image of the exposed soil using LSMM, we used IDRISI's software HIPERAUTOSIG and HYPERUNMIX modules. HIPERAUTOSIG automatically creates spectral signatures and HYPERUNMIX generates the abundance images of targets from selected spectral signatures. The spectral signatures generated by the HIPERAUTOSIG module were compared to spectral signatures available in the literature for Landsat 5 TM's sensor, and four distinct elements (targets) were considered: green vegetation, non-photosynthetic vegetation, soil, and shadow/water. The soil spectral curve was selected from the study made by Demattê et al. (2004) on Quartzipsamments. The spectral responses of the other elements were selected from studies developed in Amazônia by Adams et al. (1995) and Numata et al. (2007).

To eliminate the shadow effect caused by lighting differences during image acquisition, ES abundance image was normalized using Equation 1:

$$ES_{Norm.} = ES/(1\text{-}Shadow) \qquad (1)$$

Where:

ES = abundance image of the exposed soil;

Shadow = abundance image of the shadow.

RESULTS AND DISCUSSION

Assessment of LSMM's performance

The spectral curves produced by green vegetation (GV), non-photosynthetic vegetation (NPV), soil and shadow/water selected for the study area are shown in figure 2.

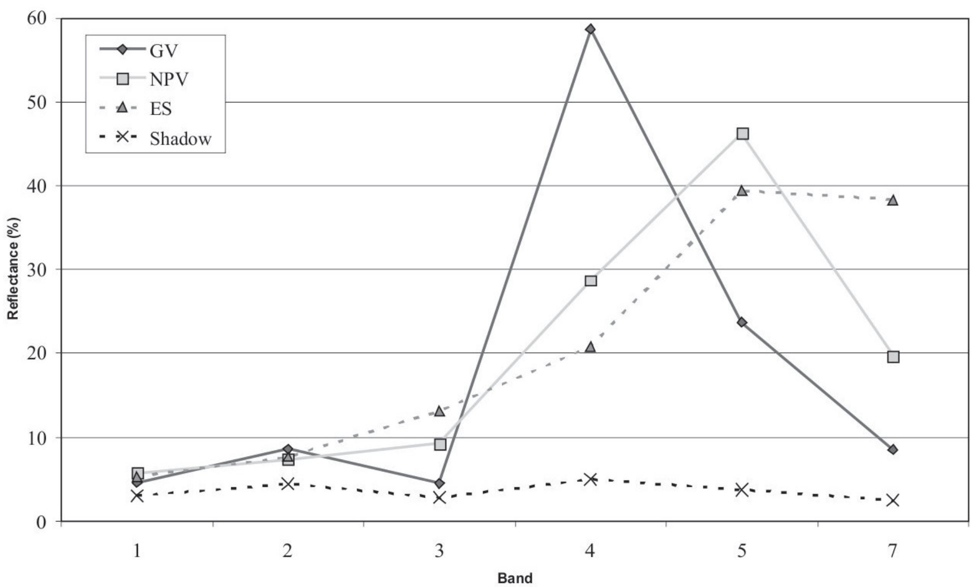

Figure 2 – Spectral curve for green vegetation (GV), non-photosynthetic vegetation (NPV), exposed soil (ES) and shadow, obtained from images of the year 2010

The error image or RMSE (Root Mean Square Error) image average was of 0.0763 (7.63%), which indicates good quality of the targets (endmembers) used in the LSMM processing.

LSMM's performance was assessed using the global accuracy and Kappa indices, and considering as absolute truth the information on 45 pastures on RQ at the BAT, which were observed during a field study in April 2010. The parameter considered to assess the degradation level of these pastures in terms of erosion risk was the percentage of exposed soil.

The global accuracy was of 0.80, and the Kappa index was of 0,687. The agreement level of the Kappa index was substantial and significantly different from 0 to 99% probability.

Pasture degradation level mapping

The degradation classes (levels) of the pastures grown on RQ at the BAT in the year 2010 obtained using LSMM are shown in figure 3.

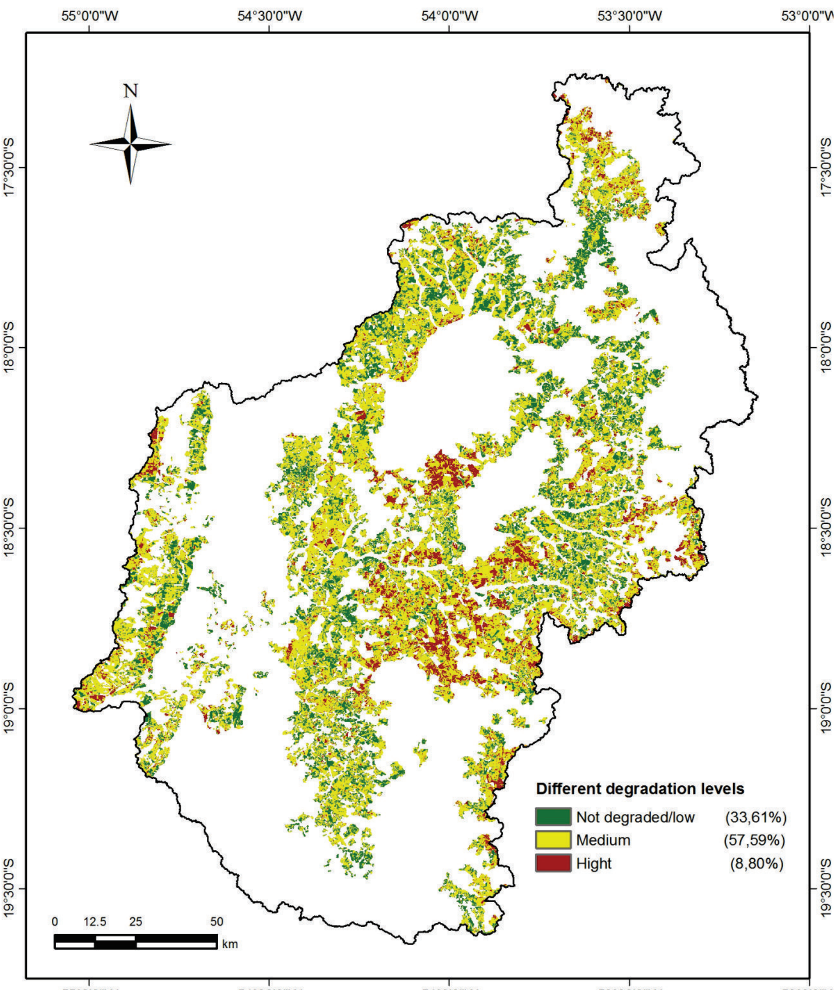

Figure 3 - Map of the different degradation levels of the pastures planted on Quartzipsamments at the Alto Taquari watershed in 2010

In table 1, we present the main characteristics (parameters) of the pasture areas with different degradation levels grown on Quartzipsamments at the BAT in the year 2010.

Table 1 - Main parameters of the different degradation levels of the pastures grown on Quartzipsamments at the Alto Taquari watershed in 2010

Main parameters	Pasture degradation level		
	Not degraded/low	Medium	High
Area (ha)	286,089	490,209	74,906
Exposed soil average (%)	13.05	30.09	55.88

Pastures with medium degradation level were predominant in RQ pasture areas at BAT in 2010 (57.6%). About 286 thousand hectares (33.6%) of the pastures showed low or no degradation level. Approximately 75 thousand hectares (8.8%) of the pastures on RQ showed high degradation level, with elevated soil loss rates, and deserve special attention as to their management and the adoption of conservationist soil practices (GALDINO, 2012).

Figure 4 shows the distribution of declivity classes, in percentage, in the study area.

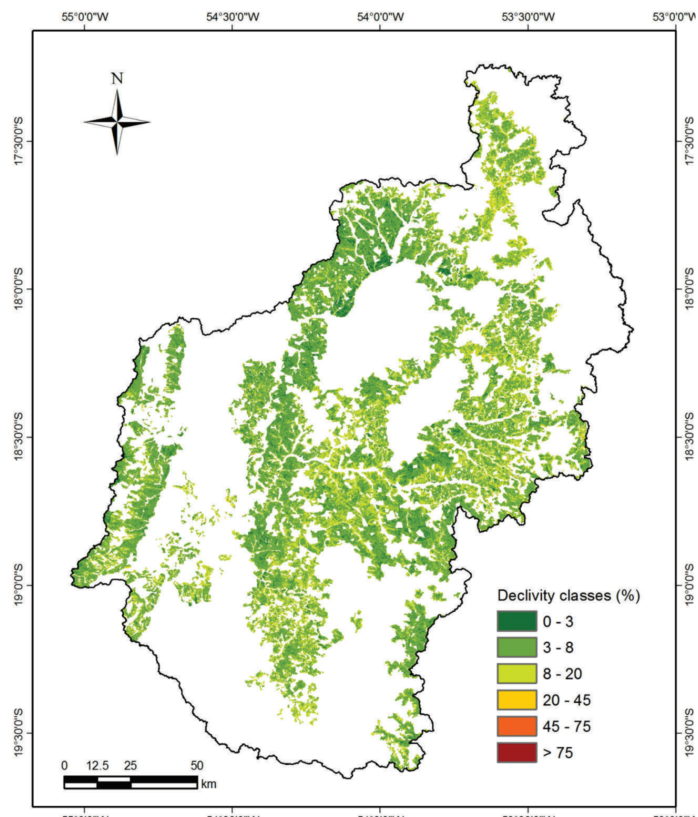

Figure 4 – Map of declivity classes, in percentage, in areas of pastures planted on Quartzipsamments at the Alto Taquari watershed

To assess the effect of declivity on the degradation level of pastures planted on RQ, we confronted these data with the declivity class distribution according to the classification proposed by Embrapa (1979). The distribution, in percentage, of the declivity classes discriminated by pasture degradation level is shown in table 2.

Table 2 – Distribution of declivity classes discriminated by pasture degradation level on Quartzipsamments at the Alto Taquari watershed in the year 2010

Class	Declivity (%)	Distribution (%) of pasture degradation levels*		
		Not degraded/low	Medium	High
Plain	0 - 3	8.52	9.79	8.70
Mild slope	3 - 8	62.94	65.17	62.01
Slope	8 - 20	27.32	24.63	28.90
Strong slope	20 - 45	1.14	0.41	0.38
Mountain	45 - 75	0.08	0.01	0.00
Escarpment	> 75	0.01	0.00	0.00

* Value obtained from the ratio of the crossing of pasture area x declivity class divided by the total area of the different pasture degradation levels.

Table 2 and figure 4 evidently show that most part, i.e. approximately 2/3 of the pasture areas on RQ at the BAT are grown on mild slopes (3 to 8% declivity), and that the degradation level of these pastures occur indistinctively in terms of topography conditions.

CONCLUSIONS

The percentage of exposed soil in pasture areas is a potential indicator of the different degradation levels of these pastures in terms of hydric erosion.

The soil abundance image obtained by LSMM enables a qualitative assessment of different levels of soil exposure to the erosive action of rainfall.

Most (57.6%) pastures grown on sandy soils at the BAT in 2010 showed a medium level of degradation. Pastures with a high level of degradation covered about 9% of the sandy soil areas, and approximately 1/3 of the pastures showed a low level of degradation or no degradation.

Approximately 2/3 of the pastures on RQ areas at the BAT are grown on mild slopes (3 to 8% declivity), and no correlation was found between the topography and the degradation level of the pastures.

RECOMMENDATION

To reduce the percentage of exposed soil, and consequently the risk of hydric erosion, we recommend the recovery of areas with degraded pastures at the BAT by means of pasture renovation and adoption of adequate management practices in the areas covered by these grasses, as well as the deployment of conservationist soil practices such as terracing.

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