GEOTECHNOLOGIES APPLIED TO MAPPING OF ENVIRONMENTAL FRAGILITY IN THE DESBARRANCADO RIVER BASIN, MS

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Abstract

This paper aims to analyze the degree of potential and environmental fragility of the Desbarrancado river basin. To develop this work remote sensing data were used and spatial analysis techniques in Geographic Information System and field survey. The results showed that the potential fragility of the watershed area of the Desbarrancado river consists of three categories: low, medium and strong, occupying 48.7%, 49.4% and 1.9% of the basin area, respectively. The environmental fragility revealed four categories: low, medium, high and very high, occupying 11.15%, 82.32%, 4.97% and 1.56% of the basin area, respectively. It is concluded that the watershed of the Desbarrancado river presents a prevalence low and medium degree potential fragility, however when considering the anthropic action has an enlargement of approximately 37% of the area occupied by the medium and high fragility and reduced in the same proportion of areas naturally low fragility, revealing that the predominance of cattle raising activities promoted significant changes in the balance ecodynamic area.

Keywords: Environment. Remote sensing. Land use. Deforestation. Erosion.

Resumo

Geotecnologias aplicadas à cartografia da fragilidade ambiental da bacia hidrográfica do rio Desbarrancado, MS

O presente artigo tem por objetivo analisar o grau de fragilidade potencial e ambiental da bacia hidrográfica do rio Desbarrancado/MS. Para o desenvolvimento deste trabalho foram utilizados dados de sensoriamento remoto, técnicas de análise espacial em Sistema de Informações Geográficas e trabalho de campo. Os resultados mostraram que a fragilidade potencial da bacia hidrográfica do rio Desbarrancado é composta por três categorias: fraca, média e forte, ocupando 48,7 %, 49,4% e 1,9% da área da bacia, respectivamente. A fragilidade ambiental revelou quatro categorias: baixa, média, alta e muito alta, ocupando 11,15%, 82,32%, 4,97 % e 1,56% da área da bacia, respectivamente. Conclui-se que a bacia do rio Desbarrancado apresenta um predomínio de baixo e médio grau de fragilidade potencial, entretanto quando considerada a atuação antrópica tem-se uma ampliação de aproximadamente 37% da área ocupada pelas médias e altas fragilidades e redução na mesma proporção das áreas naturalmente de baixa fragilidade, revelando que o predomínio da atividade agropecuária promoveu mudanças significativas no equilíbrio ecodinâmico da área.

Palavras-chave: Meio ambiente. Sensoriamento remoto. Uso da terra. Desmatamento, erosão.

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INTRODUCTION

Over the recent decades, the scientific community has been growing aware of the importance of studies that relate the biotic and abiotic elements so as to understand the way the major natural systems function and thus to identify a social and environmental development that can accommodate the strengths and weaknesses of the environment. The production of research studies related to environmental interaction is being promoted and techniques and methodologies that adopt the watershed as a planning unit are especially encouraged (LIMA, 2008; SAFFORD, 2010; BOTELHO and SILVA, 2011; VALLE JUNIOR et al., 2014). This clearly defined territorial unit naturally becomes the starting point for an integrated management including all the natural resources that constitute this system, like water, soil and vegetation (ROSS and DEL PRETE, 1998). In this light, the basin is perceived as a unit of analysis and strategic environmental planning in the context of how it fits into the framework of modern society, based on the use of its natural resources. This involves the space where the man x nature interaction occurs and the different ways in which natural resources are utilized by society. Therefore, the lack of a systemic vision and a policy to manage the water resources poses impediments in the creation and implementation of projects which endeavor to integrate the physical and human elements like policy management and the economic and preservation aspects present in the watershed (TUNDISI, 2011).

Interestingly, every area on the earth's surface is part of a watershed (NASCIMENTO; VILLAÇA, 2008) and therefore, anthropogenic changes cause environmental damage that result in problem in the water cycle and sedimentological system (LIMA, 2008). Therefore, it becomes necessary to develop the methods aimed at striking a balance between the availability of the physical and social elements, with an awareness of the limits of environmental usage (ALMEIDA; GUERRA, 2013).

In order to support land management it was necessary to involve the physical planning of human activities on the territory, including in river basins. It was Ross (1994; 2012) who proposed the integrated analysis of physical and man-made elements as their potential and environmental fragility, following the precepts of the ecodynamic theory advocated by Tricart (1977). From a conceptual perspective, the potential fragility is defined as the natural vulnerability of an environment according to their physical characteristics, such as commotion topography and soil type. The emerging or environmental fragility, besides considering the physical, also includes the degrees to which the protection of the different types of land use and land cover influence on the environment (KAWAKUBO et al., 2005).

Over the last decade especially, the advancements made in Brazil, particularly in the field of geotechnology, coupled with the free availability of remote sensing products, have strongly driven the development of environmental diagnostics and prognostics. Keeping this in view, Crepani et al. (2001; 2008) showed that geotechnologies and remote sensing data stored in the Geographic Information System (GIS) could be useful in supporting the planning and territorial management. These results could form the basis on which guidelines for activities in the territory could be drawn up, keeping in mind the fragility and vulnerability to the natural and environmental landscape.

In the Mato Grosso do Sul (MS) State, especially in the Upper Paraguay River Basin, despite some initiatives presented in the last decade (OLIVEIRA et al., 2012; BARBOSA; BACANI, 2012; BACANI; LUCHIARI, 2014; SILVA NETO, 2014; PIRES et al., 2015), there is still a great lack of researches with a focus upon an analysis of the environmental fragility in river basins. In the context stands out the Desbarrancado river basin, which is a sub-basin of the Miranda river, whose waters flow towards the Pantanal wetland, and which is at present going through an intense transforming phase related to the intensification of farming. Thus, it becomes extremely important to construct an environmental diagnosis of the Desbarrancado river basin by utilizing of geotechnology.

OBJECTIVE

The objective of this work was to analyze the environmental fragility of the Desbarrancado / MS river basin using the GIS techniques and remote sensing data.

MATERIAL AND METHODS

The Desbarrancado river basin covers approximately 16,440 hectares, and comprehends parts of Guia Lopes da Laguna and Maracaju municipalities, located in the southwest region of the Mato Grosso do Sul State, Brazil, between the southern latitudes of 21º26’00'’ and 21º33’20'’ and west longitude of 55º45’40'’ and 55º58’30'’ (Figure 1). The Desbarrancado river has a tributary on the right bank of the Santo Antônio river, which is part of the Miranda River basin.

The Desbarrancado river basin comprises the basaltic rock types in the Serra Geral Formation (SEMAC, 2011). The bedside drainage is located in the Maracaju-Campo Grande Plateau, with an east to west water flow for 30 kilometers.

Data from a GeoMS Project (SILVA et al., 2011) reveals that the study area is located in a phytogeographic region, nestled between the Cerrado biome and seasonal forest (Atlantic Forest) of a diverse vegetation type, in which dense woody vegetation (Savanna) alternates with areas of natural or cultivated pasture.

A geographic database was organized using ArcGIS 10.2® software with following materials:

- Radar interferometric image taken from the geomorphometric database TOPODATA (VALERIANO, 2008), referring to grid 21_57_ZN (.GeoTIFF), of approximately 30 m spatial resolution.
- Landsat-8 satellite image, OLI sensor, path/row 225/75, dated passage on April 7, 2014. We employed bands 4 (B), 5 (G) and 6 (R) with a spatial resolution of 30 m and band 8 (panchromatic) with a spatial resolution of 15 m (USGS, 2014).
- Data from rainfall stations (EMBRAPA, 2014).
- Vector files of the priority areas for conservation of the biodiversity (SISLA, 2007).
- Vector files of soil classes mapping of the MS State (SISLA, 2007).
- Vector files mapping of vegetation cover of Mato Grosso do Sul (SILVA et al., 2011).

The radar interferometric SRTM (Shuttle Radar Topography Mission) images were used to automatically delimit the watershed in the Global Mapper software. Next, in vector format was exported to ArcGIS, where was made adjustments by contour lines at an equidistance of 20 m.

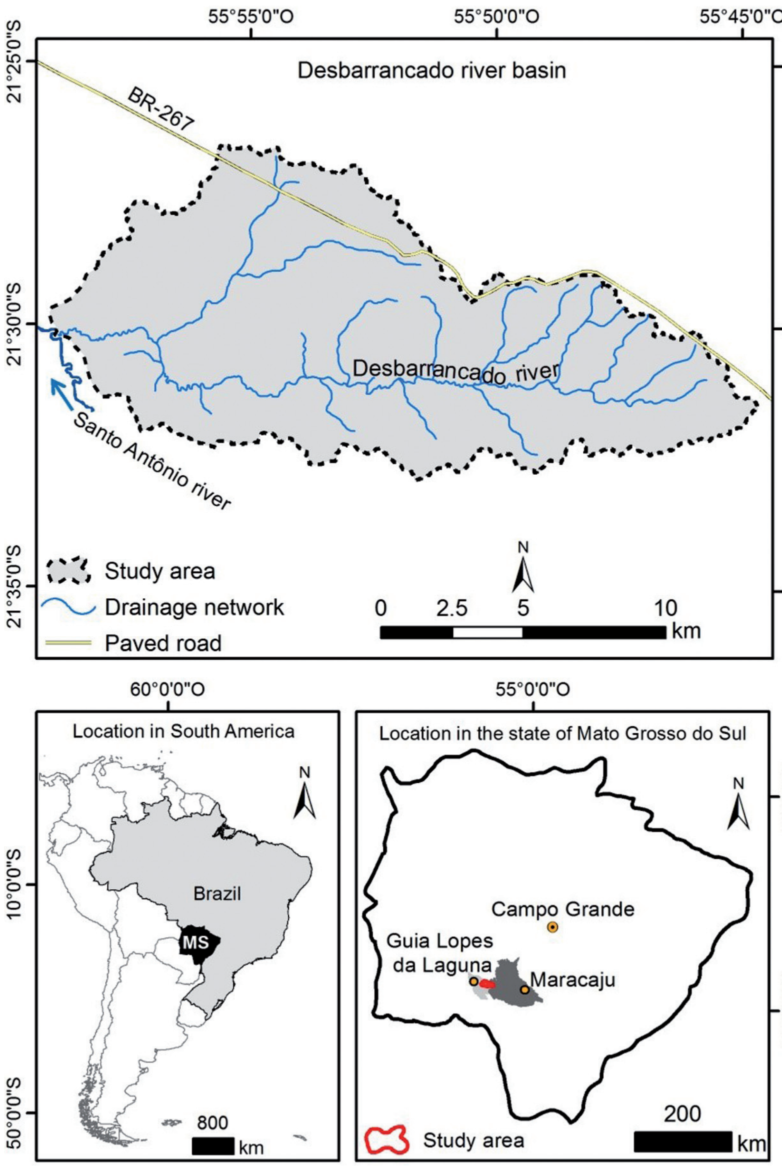

Figure 1 - Location of the study area

Source: IBGE (2103). Geographic projection. Datum SIRGAS (2000).

The methodological procedures including the materials and methods used are shown in Figure 2.

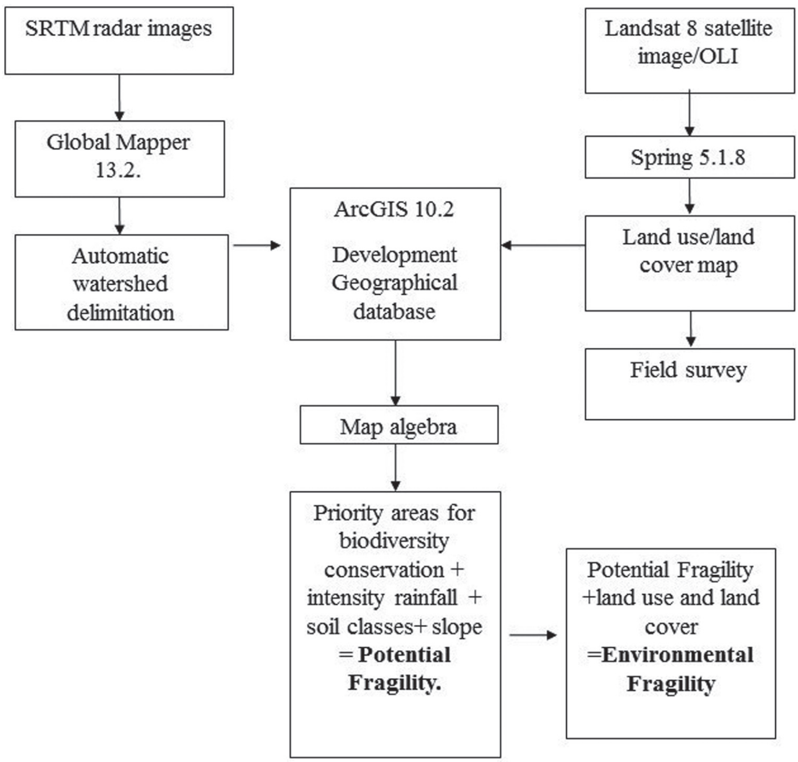

Figure 2 - Workflow of the methodological procedures adopted in the implementation of the study

Using radar images, the slope percentage in the study area (%) was organized in the ArcGIS software. The ranges of slope classes were adapted according to Ross (1994).

The rainfall data were obtained from the site of Brazilian Agricultural Research Corporation (EMBRAPA, 2014), collected by National Water Agency (ANA). The average annual total rainfall of eight stations was used in the study area (Table 1). The rainfall variability map was compiled employing the IDW (Inverse Distance Weighted), interpolation method, using the mean annual precipitation.

Table 1 - Rainfall stations

Station Name	Lat./Long.	Annual Average (mm)
Jardim station	s 21°26'25", w 56°05'24"	1,287.4
Maracajú station	s 21°37'02", w 55°08'11"	1,395.9
Nioaque station	s 21°08'58", w 55°49'27"	1,152.6
Bonito station	s 21°06'55", w 56°31'01"	1,380
Antônio João station	s 22°11'08", w 55°56'31"	1,571
Capão Bonito station	s 21°10'53", w 54°44'38"	1,293.5
Sidrolândia station	s 22°06'32", w 56°31'35"	1,325
Bela Vista station	s 22°06'32", w 56°31'35"	1,325

Source: EMBRAPA (2014).

For calculate the fragility of the watershed in relation to rainfall, was used the proposition of Crepani et al. (2001), by evaluating the effect of rainfall intensity. However, the method proposed by Ross (1994) to identify the potential fragility, did not involve the rainfall intensity. For this reason methodological adaptation was implemented (Table 2).

Table 2 - Methodological adaptation to calculate the weight of the variable rainfall

Methodology	Crepani et al. (2001)	Ross (1994)
Weight	3	5
	N	*X*

Soil classes were obtained from the Interactive System Database Support Environmental Licensing (SISLA), a free online platform available at the Institute for the Environment of Mato Grosso do Sul (IMASUL), as well as information on priority areas for biodiversity conservation, with the data compiled from the Ministry of Environment (BRASIL, 2007).

The Landsat-8 satellite image from was used to produce the thematic map of land use and land cover in the watershed for 2014. This step was conducted in keeping with the methodological procedures proposed by Novo (2010), Jensen (2009) and Moreira (2007), concerning the Digital Image Processing (DIP): pre-processing, enhancement and classification.

GeoMS project data were used to facilitate the identification of the vegetation cover, (SILVA et al., 2011), informing the main vegetation classes of Mato Grosso do Sul (MS). It was used to color in the cartographic editing following the technical procedures described in the land use Technical Manual of Brazilian Institute of Geography and Statistics (IBGE, 2013).

After the elaboration of thematic maps of soils, rainfall intensity, slope, priority areas for biodiversity conservation and land use and land cover, reclassification was done to show the different degrees of fragility as proposed by Ross (1994; 2012), (Table 3).

Table 3 - Weights and categories of potential and environmental fragility

Weight	Hierarchical Categories
1	Very Weak
2	Weak
3	Medium
4	Strong
5	Very Strong

Source: Adapted from Ross (1994).

In next step proceeded to the weighted overlay (map algebra) that initially resulted in the potential fragility map, which originated from a combination of soils, rainfall intensity, slope and priority areas for biodiversity conservation. To generate the environmental fragility map was performed the weighted overlay from combination of potential fragility and land use and land cover maps.

RESULTS AND DISCUSSION

The figure 3 shows the spatial distribution of the five slope classes, revealing a predominantly flat relief (62.04% of the basin area). This feature tends to facilitate the land use to develop agricultural activities, extensive plantations, construction of cities, among others (GONÇALVES et al., 2011; OLIVEIRA et al., 2012).

Thus, the most favorable to the occupation areas in the watershed, from the relief perspective, had a slope from 0 to 6% and 6 to 12% and occupied an area of 14,711.96 ha (89.48%). Only 10.52% have some type of restriction, because they are located in areas situated in the hills in the center-east direction of watershed (Table 4). These data reinforce the need to adopt preventive measures regarding land use, because the relief, although showing higher slopes near the springs, dominates the lower slopes, which encourages the expansion of agricultural activities.

The analysis of rainfall data revealed that the rainfall was concentrated between the months of September to May, totaling to nine months precipitation, with a monthly average between 142-144 mm. Among these months, December is regarded as the highest concentration of rainfall. The rainfall intensity watershed study was classified as a weak potential fragility, because the rains are relatively well distributed throughout the year. This enabled the classification of the rainfall intensity of 1.4 with respect to the vulnerability to erosion and soil.

However, soils without vegetation cover or lack of conservation practices on agricultural crops increases the effects of surface erosion (ARAI et al., 2010). Among the soil classes present in the base (Figure 4) the Luvisol occupies 57.48% of the area, located between the middle and lower course (Table 5). This soil class has the physical characteristics of good permeability, but with limitations for agricultural use, especially the use of heavy machinery and are susceptible to erosion (EMBRAPA, 2006), allowing classifies it as medium potential fragility.

The Quartzarenic Neosol (Entisol) extends 30.33% of the watershed, observed from the source to the portion of the course middle of river basin, whose potential fragility is very high (ROSS, 1994; ROSS, 2012). This type of soil is shallow and susceptible to erosion when managements improperly. For that reason, must be careful with intensity activities practiced on it (EMBRAPA, 2006).

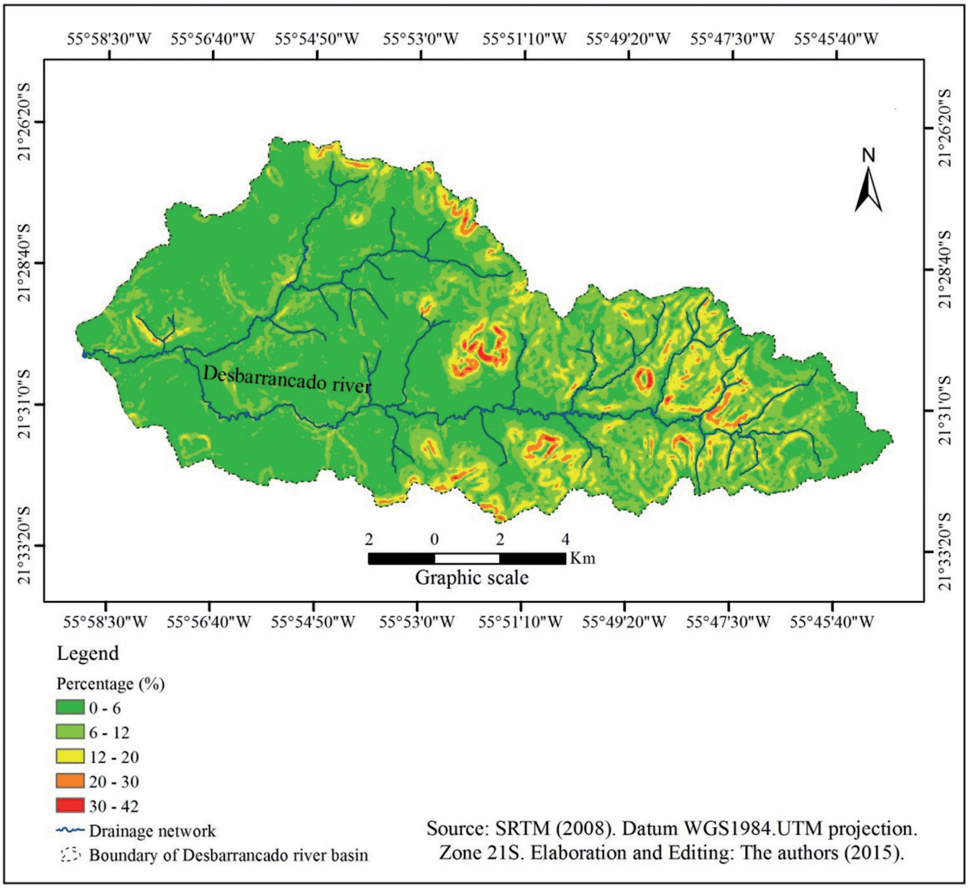

Figure 3 - Slope of the Desbarrancado river basin

Table 4 - Slope classes of the Desbarrancado river basin

Slope (%)	Area (ha)	Weight (Category)
0 – 6	10,200.80	1 (Very Weak))
6 – 12	4,511.16	2 (Low)
12 – 20	1,391.95	3 (Medium)
20 – 30	306.25	4 (Strong)
30 – 42	29.84	5 (Very Strong)
Total	**16,440**	**-**

Table 5 - Percentage of area occupied by soil class

*Soil Class	Area (ha)	Weight and Category
Red Latosol (Rhodic Ustox)	971.11	1 (Very Weak)
Argisol	865.69	2 (Low)
Argiluvic Plinthosol	170.21	5 (Very Strong)
Quartzarenic Neosol (Entisol)	4,987.40	5 (Very Strong)
Luvisol	9,445.59	3 (Medium)
Total	**16,440**	**-**

*Source: SISLA (2007).

Based on the priority areas for conservation and sustainable use of natural resources (BRASIL, 2007) the Desbarrancado river basin has two areas with differing degrees of importance: very high and insufficiently known. The area considered very high for biodiversity conservation is located between the middle course and the springs. Those areas of the basin reveal the highest elevations characterized by hills and slope rates ranging from 12 to 30%. The class designated as insufficiently known, shows a low slope between 0 and 6%, which features a flat relief. This area found between the middle and lower course, includes areas of woody vegetation with good conservation status near the river banks. These classes act as parameters for the future, showing suitable locations to orderly way of occupation or indicating the establishment of Conservation Units (CU's), whit can be created in order to protect the local biodiversity (BRASIL, 2007; PIRES et al., 2015).

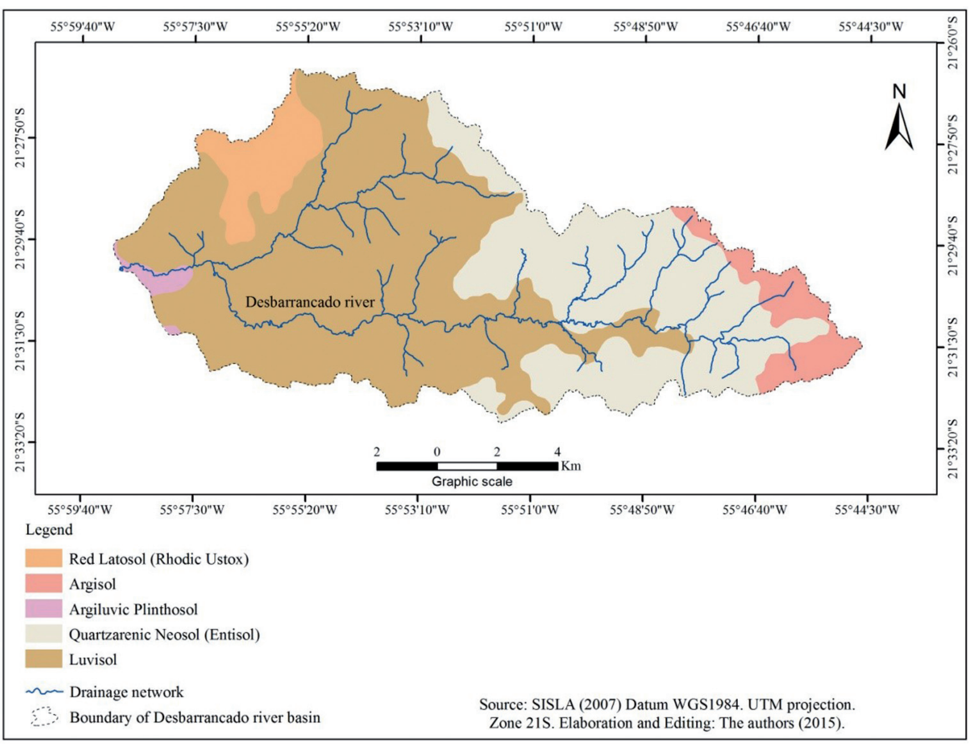

Figure 4 - Soil classes in the Desbarrancado river basin

The potential fragility in the watershed is composed of three categories: low, medium and high (Figure 5).

The area with weak potential fragility extends over 48.7% of the watershed total, and is located mainly in the middle and lower course. This area is strongly occupied by pasture and associated with a low degree of slope. Similar results were found by Cabral et al., (2011) in the Doce River basin in Goiás State, where despite being considered low fragility, it is strongly occupied by agricultural activities, and therefore warrants attention and monitoring, because these factors tend to increase the degree of fragility (BACANI; LUCHIARI, 2014).

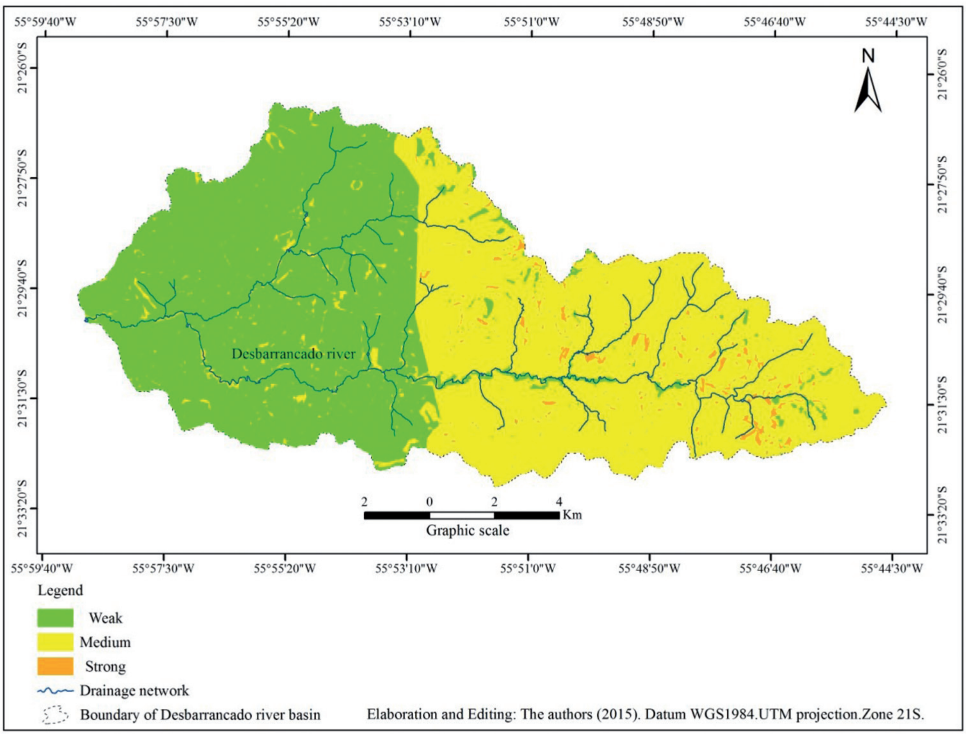

Figure 5 - Potential fragility of the Desbarrancado river basin

The medium potential fragility category occupies the largest area of the basin (49.4%), where soft and wavy reliefs predominate interspersed with some flat areas, with slopes above 6%. The areas mapped as potential fragility strong are regions found in small areas throughout the watershed and extend across only 1.9% of the area. Much of this area was considered a high priority for biodiversity conservation (BRASIL, 2007), due to the topographic factor characterized by the presence of steep slopes, hills and hills. Similar results were found by Gonçalves et al. (2011) in the Dourados River basin in MS State.

In the areas of potential fragility average and strong predominate the Quartzarenic Neosol (Entisol). A similar result was obtained by Oliveira et al. (2012) in areas of potential fragility medium and high in the São João stream basin in MS State, associated with the presence of Quartzarenic Neosol (Entisol) and strong occupation of the land for pasture.

Batista and Silva (2013) proposed that areas with high elevations and slopes hamper human occupation and therefore, often manage to keep preserved native vegetation. Areas with those characteristics sustain much of the local biodiversity and maintain the ecodynamic balance of the system (TRICART, 1977). However these areas are surrounded by large land tracts intended for agricultural activities, mainly pasture.

In the watershed under study, ten land use and land cover classes (Figure 6) were mapped as follows: Savanna Woodland, Savanna (Cerrado) with Gallery Forest, Savanna (Cerrado) without Gallery Forest, Alluvial Forest, Deciduous Forest and Secondary Vegetation, bare soil, water, pasture and agriculture (Table 6).

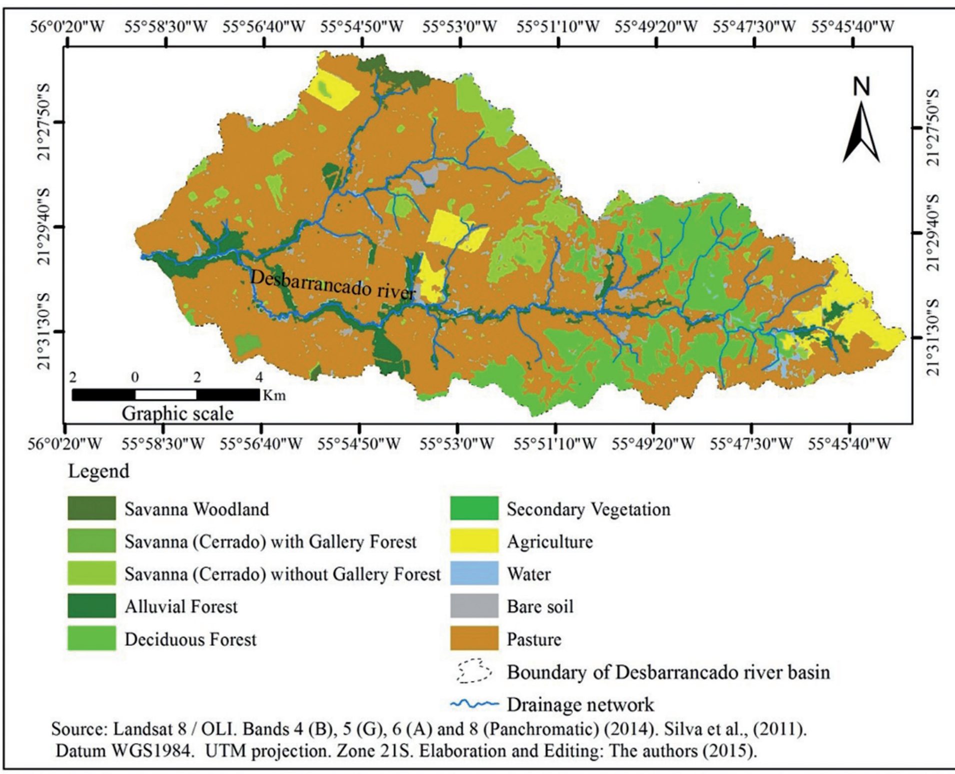

Figure 6 - Land use and land cover classes

The pasture class predominates most of the area and equivalent to 66.5% of the watershed area. (Table 6). It supports exotic pasture for the practice of cutting and dairy farming. The pasture, evaluated as having medium fragility in the watershed, presents good condition of conservation and employment of conservation practices. However, much of the pasture is grown in Quartzarenic Neosol (Entisol) classified as soils of very high fragility and therefore requires great attention regarding management use and conservation, especially in relation to soil loss (OLIVEIRA et al., 2012).

Agriculture occupies 4.3% of the watershed. It was classified as strong fragility area and it is situated close to the springs and lacks any implementation of conservation measures such as tillage and contour lines to prevent soil erosion. The absence of these techniques primarily affects the soil, leaving it often susceptible and open to surface erosion by rain (BERTOL et al., 2004; FRANCISCO, 2012).

Therefore, the practice of agriculture should be cared for, because it is one of the economic activities that will cause environmental imbalances if it is not developed by implementing conservation practices, mainly management methods to protect the soil (CABRAL et al., 2011; OLIVEIRA et al., 2012). Botelho and Silva (2011) state that there is a loss of natural soil fertility, which compels the application of chemical fertilizers to recover a measure of the fertility. In this scenario, as highlighted by research by Mendonça and Marques (2011), it needs pay attention with type of land use next to water sources, because this factor explains significantly on water quality.

Stands out the importance of maintaining Permanent Preservation Areas (PPA's) in the Desbarrancado river basin, since these spaces are being used for agricultural activities, including the presence of bare soil, which tends to raise the degree of environmental fragility very high.

The land cover class of tree vegetation extends across 25% of the area, and is located mainly near the canal banks and in the higher regions of the watershed. These canals were identified as being interconnected, which assists in the formation of ecological corridors and helps maintain the circulation and conservation of the local biodiversity.

Table 6 - Land use and land cover classes in the Desbarrancado river basin

Use Classes	Area (ha)	Weight Fragility
Pasture	10,940	3 (Medium)
Agriculture	720	4 (Low)
Bare Soil	260	5 (Very Low)
Water	410	5 (Very Low)
Tree Vegetation	4,110	1 (Very High)
Total	**16,440**	**-**

Bare soil areas are incorporated into the pastures and places where there is movement of pets. According to Capeche et al. (2008) the bare soil areas or those having strong erosion traces should be isolated from the other areas so that they can be reclaimed by implementing minimum measures using soil conservation practices, native or exotic reforestation to reduce or prevent advancement and evolution of erosion. The figure 7 lists out the main categories of land use and land cover found in the Desbarrancado river basin.

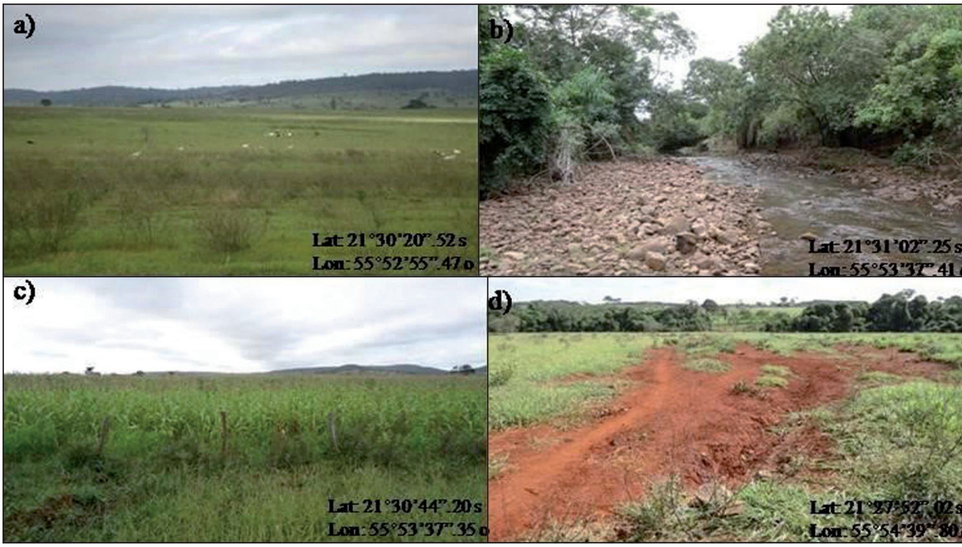

Figure 7 - Land use and land cover in the Desbarrancado river basin. Pasture (a); Vegetation (b); Agriculture (c); Bare soil (d)

Source: The authors (2015)

The Desbarrancado river basin presented four categories of environmental fragility: weak, medium, strong and very strong (Figure 8).

In the basin a predominance of the category of medium environmental fragility is observed, which extends across 82.32% of the area and is associated mainly with the hegemony of the pasture. Other studies reported similar results (BACANI; LUCHIARI, 2014; MENDONCA; MARQUES, 2011; OLIVEIRA et al., 2012) where areas with major use of pasture had the average environmental fragility dominant. However, in the Desbarrancado river basin, inadequate management with pasture farming is causing severe problems, such as soil compaction and evidence of erosive processes, including ravines and gullies (Figure 9a).

Areas with a degree low of environmental fragility extended across 11.15% of the study area, and were mainly found between low and middle course. Occupied by pastures, under good management conditions and with large areas of vegetation close to the canal banks, however these areas should be monitored and the intensity of use controlled.

The high degree of environmental fragility visible in the east part of the watershed, occupying 4.97% of the area, is found mainly in the headwater areas of the main tributaries of the basin (Figure 9b). The actual springs are surrounded by sugarcane plantation which is a cause for concern, because it poses a conservation risk to the Permanent Preservation Areas (PPA's). It also contributes to the erosion and soil depletion as well as the pollution of the water courses through pesticides. According Botelho and Silva (2011), several of these chemicals may be retained in the soil for up to 10 years, affecting the microorganisms living there and polluting in springs and water resources.

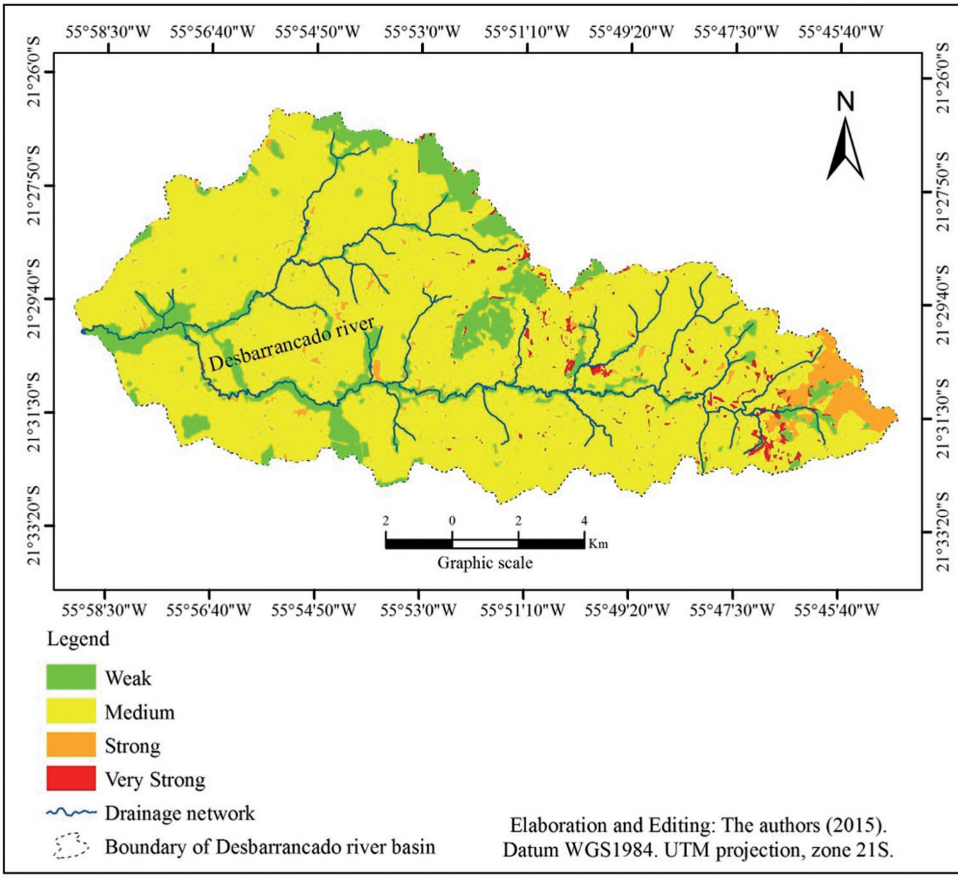

Figure 8 - Environmental Fragility in the study area

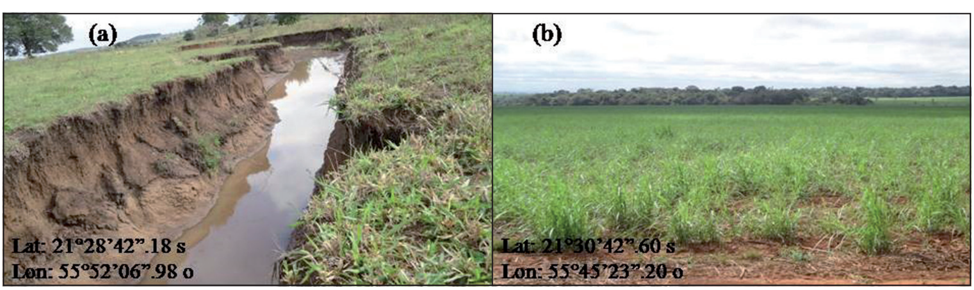

Figure 9 - (a) Gully in the study area and (b) Sugarcane plantation close to the springs

Source: The authors (2015).

The area with a very high degree of environmental fragility (1.56%) are mainly found in the steeper regions (hills and valleys) with a slope between 12-42%, which still retains the remaining natural vegetation cover, and therefore must be kept and preserved.

The conservation of vegetation is essential to ensure ecodynamic stability. This ensures the preservation of many natural resources, such as the protection of soil and water in regions of springs and margins, and reducing erosion and pollution by chemicals (MENDONÇA; MARQUES, 2011). Thus, the mapping of environmental fragility revealed that several portions of the watershed should be used cautiously, especially in areas where the pasture practices on fragile soils and agriculture next springs. The other areas need to be constantly monitored to put a stop to any further increase in environmental fragilities.

CONCLUSION

In the Desbarrancado river basin there was a predominance of medium environmental fragility, resulting from natural physical aspects in the area and the hegemonic use of pasture, a fact that makes preponderant the achievement of measures for the preservation and recovery of the degraded areas.

The rise in the economic activities linked with agriculture, has altered the landscape of the Desbarrancado river basin due to its environmental fragility, one reason for the triggering of erosion processes.

It is recommended the establishment of initiatives to reduce the increased fragility, through compliance with the prevailing environmental laws in order to protect the fragile areas.

The areas with high environmental fragility should be wisely and cautiously used, especially the agriculture areas where conservation practices are not implemented. In areas of very strong environmental fragility, the caution of type land use is recommended, with immediate need to recover and subsequently preserve, because it is mostly PPA’s near springs or areas being degraded, such as the pastures.

The application of the GIS techniques enabled the construction of a cartographic representation which in turn enabled the satisfactory analysis of the potential and environmental fragility, which contributed to the preparation of proposals and environmental planning recommendations in the Desbarrancado river basin.

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