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NATURAL AND ENVIRONMENTAL VULNERABILITY OF THE JAURU RIVER BASIN – MATO GROSSO STATE, BRAZIL

VULNERABILIDADE NATURAL E AMBIENTAL DA BACIA HIDROGRÁFICA DO RIO JAURU – MATO GROSSO, BRASIL

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ABSTRACT

The disorderly use of land is currently one of the main causes of environmental problems. From this perspective, the objective of this study was to determine the natural and environmental vulnerability of the Jauru river basin in the Brazilian state of Mato Grosso. This goal was made from the perspective that the results generated contribute to environmental planning and management, considering that the Jauru river is tributary of the Paraguay river, responsible for the flooding of the Pantanal plain and, that possible impacts caused by the basin may compromise the dynamic equilibrium of the Pantanal's flood pulse. The model of assessment of natural and environmental vulnerability was adopted, with the identification of the following environmental characteristics: geology, slope, agricultural aptitude and vegetation cover and land use. Data were related through Geographic Information Systems to generate natural and environmental vulnerability maps. It was verified, through the data obtained, that in both vulnerabilities studied there was a predominance of the middle class, mainly resulting from the presence of fragile soils. Also, the predominance of the classes of agricultural aptitude found in the basin, as well as the suppression of the natural vegetation to expand the pasture areas. It was concluded that the areas covered by natural vegetation and/or pastures, in the Jauru river basin, present average natural vulnerability and state of medium to high environmental vulnerability, evidencing that livestock, the main activity regional economic development, has been developed in disagreement with environmental aptitude, contributing to the elevation of the state of environmental vulnerability in the basin.

Keywords: geotechnologies; environmental analysis; land use; Pantanal.

RESUMO

O uso desordenado da terra é, atualmente, uma das principais causas de agravos dos problemas ambientais. Nessa perspectiva, objetivou-se nesse trabalho determinar a vulnerabilidade natural e ambiental da Bacia Hidrográfica do Rio Jauru, no estado brasileiro de Mato Grosso. Tal meta foi realizada sob perspectiva de que os resultados gerados contribuam ao planejamento e gestão ambiental, considerando que o rio Jauru é tributário do rio Paraguai, responsável pelo alagamento da planície pantaneira e, que possíveis impactos causados na bacia podem vir a comprometer o equilíbrio dinâmico do pulso de inundação do Pantanal. Foi adotado o modelo de avaliação de vulnerabilidade natural e ambiental, procedendo-se a identificação das seguintes características ambientais: geologia, declividade, aptidão agrícola e cobertura vegetal e uso da terra. Os dados foram relacionados por intermédio de Sistemas de Informação Geográfica para geração dos mapas de vulnerabilidade natural e ambiental. Verificou-se, através dos dados obtidos, que em ambas vulnerabilidades estudadas houve o predomínio da classe média, resultante principalmente pela presença de solos frágeis. Também, predomínio das classes de aptidão agrícola encontradas na bacia, bem como, a supressão da vegetação natural para expansão das áreas de pastagem. Concluiu-se que as áreas recobertas pela vegetação natural e/ou por pastagens, na Bacia Hidrográfica do Rio Jauru, apresentam média vulnerabilidade natural e estado de média a alta vulnerabilidade ambiental, evidenciando que a pecuária, principal atividade econômica regional, tem sido desenvolvida em desconformidade com a aptidão ambiental, contribuindo à elevação do estado de vulnerabilidade ambiental na bacia.

Palavras chave: geotecnologias; análise ambiental; uso da terra; Pantanal.

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1 INTRODUCTION

The landscape has undergone strong and constant human interference in recent years, leading to several changes in its components and, consequently, alterations in the equilibrium state of ecological dynamics. According to Bertrand (1968), the landscape is the result of a dynamic and, therefore unstable, combination between physical, biological and anthropic elements that, when reacting to one another, constitute an environment.

Therefore, when assessing the landscape, it is necessary to consider its dynamics and instability, since environmental disturbances due, in large part, to anthropogenic actions, can cause irreversible landscape damage. Because of this, landscape dynamic monitoring applying indicators is essential for the creation and application of more sustainable management models (DASSOLER *et al*., 2018; KREITLOW *et al*., 2016).

Studies on environment vulnerability are understood as natural vulnerability assessments, in the present study determined as "the degree of stability of physical and biotic elements, considering the intensity, dynamics and magnitude of the action of morphogenetic, pedogenetic and phytosuccess processes, acting on each ecodynamic unit" (ZANELLA; DANTAS; OLÍMPIO, 2011, p.15). Meanwhile, environment vulnerability should also be understood through the definition of environmental vulnerability, which is "the ability of the environment to respond to adverse effects caused by anthropogenic actions, varying according to their natural and human characteristics" (ZANELLA; DANTAS; OLÍMPIO, 2011, p.15). Environmental vulnerability directly affects environmental stability and quality. In this sense, studies on the environment vulnerability through the two aforementioned concepts have become increasingly necessary, since they result in a wide range of information concerning landscape structure, based on its characteristics, favoring territorial planning and ordering processes (RITTERS *et al*., 1995; TREVISAN *et al*., 2018).

In this context, the adoption of hydrographic basins as analysis units is adequate and pertinent to these assessments, since these are systemic environments that "integrate a joint view of the behavior of the natural conditions and the human activities developed within" (GUERRA and CUNHA, 1996, p.353). This provides an effective analysis of anthropogenic impacts and aids in developing intervention actions based on real criteria for the rational planning of natural resources through the elaboration of strategic hydrographic basin management plans (BUENO *et al*., 2011; RAMOS *et al*., 2018).

To this end, geotechnology data collection and analysis tools are important means to provide relevant information for the assessment of environmental conditions. Such tools enable complex analyses by integrating data from various sources through georeferenced databases (BATISTELLA *et al*., 2011). These tools and analyses make it possible to automate cartographic document production, offering several advantages concerning environmental and territorial management leading to high efficiency, precision and quality of spatialized information (GOUVEIA *et al*., 2015).

As the Jauru River is one of the main tributaries of the Paraguay River, which receives waters from all other UPG water courses, providing the flooding pulse dynamics of the Pantanal plain, and the Jauru River Hydrographic Basin (JRHB) displays significant importance as the headwaters of the Upper Paraguay Basin (UPG), where the Pantanal biome and its floodplain biome are located, an understanding of the spatial vulnerability of the Jauru River Hydrographic Basin (JRHB) is essential. Thus, the aim of this study is to determine the degrees of natural and environmental vulnerability of the Jauru Hydrographic Basin in the Brazilian state of Mato Grosso. This study will be carried out from a perspective of data and information generation that can guide actions aimed at environmental planning and activity impact monitoring.

2 MATERIAL AND METHODS

2.1 Study area

The JRHB, with a territorial extension of 11,697.72 km², is located in the Southwest Planning Region of the state of Mato Grosso (MT) (MATO GROSSO, 2017), distributed in fourteen municipalities (Figure 1), totaling 340,651 inhabitants, of which 279,956 live in the urban area and 60,695 in the rural area (IBGE, 2012). The region's economy is predominantly based on agricultural activities, which corresponds to 21% of the state's Gross Domestic Product (GDP).

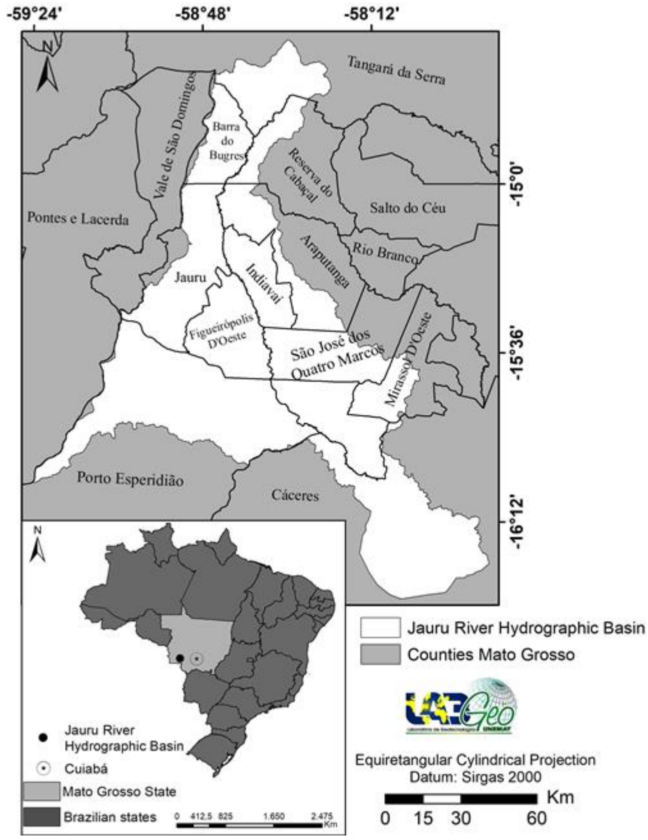

Figure 1 - Jauru River Hydrographic Basin in the national, state and municipal contexts. Elaboration: The authors (2019).

The JRHB is composed of plateau and plain reliefs, drained by the Jauru River and its tributaries. It contains transition areas between the Cerrado (Brazilian Savannah) and the Amazon Rainforest. The predominant type of climate, according to Tarifa (2011), is tropical hot and humid.

2.2 METHODOLOGICAL PROCEDURES

Based on the methodological proposed by Grigio (2003), Carrijo (2005) and Klais*et al*. (2012) regarding vulnerability evaluations, the research Geographic Database (BDG) was modeled using the ArcGis, version 10.7 software (ESRI, 2017) for cartographic base storage and compatibility and thematic information association. The cartographic geomorphology, geology and pedology bases at a 1:250,000 scale were obtained from the Secretary of State for Planning and General Coordination of Mato Grosso – SEPLAN (MATO GROSSO, 2012).

Soil classes were defined according to the Brazilian Soil Classification System (SANTOS *et al*., 2013), which also served as a basis for selecting the color pattern and cartographic conventions for the thematic map.

The aptitude map obtained at SEPLAN-MT was produced following the Agricultural Aptitude Assessment System of the Lands - SAAT (RAMALHO FILHO and BEEK, 1995). This model considers levels of technological management, admitting groups such as crops, natural and planted pastures, forestry and inapt areas indicated for flora and fauna preservation, in order to evaluate the agricultural conditions of each soil mapping unit. Some limiting factors that can hinder or even prevent land use, acting in both an integrated or separate manner, were also taken into account.

Concerning the slope map, interferometric radar scenes (SRTM – Radar Shuttle Topography Mission), band C with a spatial resolution of 30 meters were used, which were then mosaicated and cut by the study area. Subsequently, the WGS 84 datum was converted to SIRGAS 2000 and the metric coordinate system (UTM) Fuso 21 was adopted. The methodological procedures were based on Fornelos and Neves (2007). The relief phases were classified according to Santos *et al*. (2013), as follows: slope from 0 to 3% – Plain; from 3.1 to 8% – Soft Corrugated; from 8.1 to 20% – Undulating; from 20.1 to 45% – Strongly undulated; from 45.1 to 75% – Mountainous; and> 75% – Steep.

The vegetation coverage and land use map was elaborated using Landsat 8 satellite images, orbits/points 227/71 and 228-70 and 71 from 2016. The following procedures were performed: clipping, segmentation and supervised classification in the Georeferenced Information Processing System – SPRING, from the National Institute of Space Research - INPE (CÂMARA *et al*., 1996). The region growth method was used for the segmentation, whose similarity and area values were 50, respectively. The Bhattacharya classifier, with an acceptance threshold of 99.99%, was used to perform the supervised classification, where seven classes were established based on the Technical Manual for vegetation and land use (BRASIL, 2012). In the post-classification, the mapped classes were validated and/or corrected through data obtained in the field.

The integration of the physical attribute maps resulted in the development of the natural vulnerability map, which was then associated to the vegetation cover and land use map, creating the environmental vulnerability map (Figure 2).

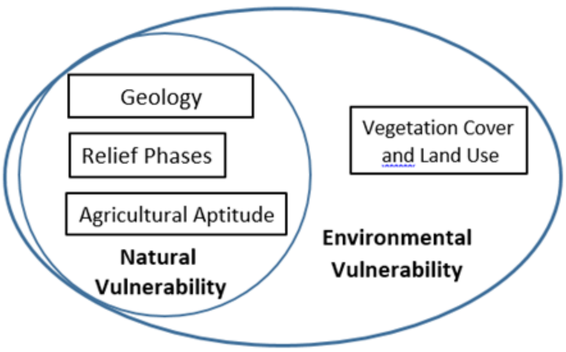

Figure 2 - Scheme for creating the Natural Vulnerability and Environmental Vulnerability maps. Elaboration: The authors (2019).

In map algebra, each cartographic representation related to environmental attributes (geology, soil aptitude, relief phase and vegetation cover and land use) was used as evidence, where its components received different weights, depending on the importance of the hypothesis in consideration. The result of this procedure is a map with areas that express a degree of relative importance, through numerical output values (CÂMARA *et al*., 2001). Thus, vulnerability degrees were distributed on a scale of 1 to 3, in 0.5 intervals. A value of 1 was attributed to environments with a predominance of pedogenesis, presenting very low vulnerability. The increasing influence of erosive processes increases vulnerability degrees, until a maximum value of 3, representing very high vulnerability environments.

Table 1 displays the weights assigned to the environmental attributes (thematic maps) of the Jauru River Hydrographic Basin used to obtain the vulnerability degrees.

Table 1 -Weights attributed to environmental attributes (Information plan) used to obtain natural and environmental vulnerabilities.

Attributes	Classes	Weight
Geology	CurrentAlluviums	3
	Araras Formation	3
	Fortuna Formation	3
	Jauru Formation	3
	Morro Cristalino Formation	3
	Pantanal Formation	3
	PugaFormation	3
	Training Formation	3
	Salto das Nuvens Formation	1
	UtiaritiFormation	3
	Xingu Complex	2
	Alkalineigneous	1
	Jauru PlateauMetavulcan-SedimentarySequences	3
	IntrusiveGuapéSuite	2
	Intrusive Rio Alegre Suite	2
Agriculturalaptitude	ABC - Lands belonging to the good aptitude tillage class at management levels A, B and C	3
	ABc - Lands belonging to the good aptitude tillage class at management levels A, B and regular at level C	3
	AB(c) - Lands belonging to the good aptitude tillage class at management levels A, B and restricted at level C	3
	2bC - Land belonging to the regular aptitude tillage class at management level B, good at level C and inapt at level A	
	2a(b) - Lands belonging to the regular aptitude tillage class at management level A, restricted at level B and inapt at level C	2
	2Bc - Lands belonging to the unsuitable tillage class at management level A, good at level B and regular at level C	2
	(b)c - Lands belonging to the unsuitable tillage class at management level A, restricted at level B and regular at level C	2
	4P – Inappropriate lands for tillage and good for planted pasture	1
	5p – Inappropriate lands for tillage and regular for planted pasture	1
	6(p) – Lands indicated for the preservation of fauna and flora with restricted aptitude for planted pasture	1
	8 (s) – Lands with restricted aptitude for Forestry	1
	000 - Land withoutAgriculturalaptitude	1

Reliefphases	Plain (0 - 3%)	1
	Soft Corrugated (3.1 - 8%)	2
	Undulating (8.1 - 20%)	2.5
	Stronglyundulated (20.1 - 45%)	3
Vegetation cover and land use	Agriculture	3
	Areasdegradedby mining	3
	Water	1
	UrbanInfluence	3
	Real Estate Management	2.5
	Forestry	2
	Vegetation	1

Organization: The authors (2019).

For the map algebra operation, an intersection between the environmental attribute maps in the ArcGis software was carried out, first resulting in a natural vulnerability map (VN) and then in the environmental vulnerability map (VA). Both VA and VN refer to the arithmetic means of the vulnerability values of each environmental attribute. The results of the arithmetic means was distributed into six classes, as proposed by Grigio (2003): unclassified (less than or equal to 0.9), very low (from 1.0 to 1.3 vulnerability), low (from 1.4 to 1.7 of vulnerability), medium (from 1.8 to 2.2 vulnerability), high (from 2.3 to 2.5 vulnerability) and very high (greater than or equal to 2.6 vulnerability).

To validate the data, fieldwork was carried out in November 2016 and July 2017. Different sites presenting different vulnerability classes were visited. All vegetation cover classes and soil use were observed in the images, whose data was used to correct the mapping. Finally, map inserts were made and the quantifiers were generated using the ArcGis software.

3 RESULTS AND DISCUSSION

A The average natural vulnerability class represented 37.16% of the basin’s extension (Figure 3A), comprising the Araras Formations, Current Alluviums, Fortuna, Pulga, Morro Cristalino, Pantanal, Raizama, Salto das Nuvens, Utiariti and Intrusive Guapé Suite. The soils in these areas are suitable for pasture with certain restrictions concerning agriculture management, presenting variable declivity, although a plain relief is predominant. The high clay content presented by the soils in this area constitutes a limitation for agricultural use, as it favors decreased infiltration and accentuates superficial deflluvium. However, high technology management can aid in correcting this limitation (LUMBRERAS *et al.*, 2015).

Low natural vulnerability is concentrated in predominantly flat areas, with restricted and regular areas for planted pasture – 6(p) and 5(p), corresponding to 30.85% of the basin. This class occurs throughout the basin. However, it is predominant in the Southwest portion, presenting HapplicPlintossols (Figure 3A). This type of soil displays limiting characteristics, such as drainage impedance and flooding periodicity, whose consequence is the formation of a plinthic horizon (SANTOS *et al.*, 2013). Nevertheless, natural vegetation as extensive grazing may be an alternative at certain times of the year. However, it is important to note that the plinthic soil tends to harden irreversibly, making soil management difficult (MARTINS *et al.*, 2006).

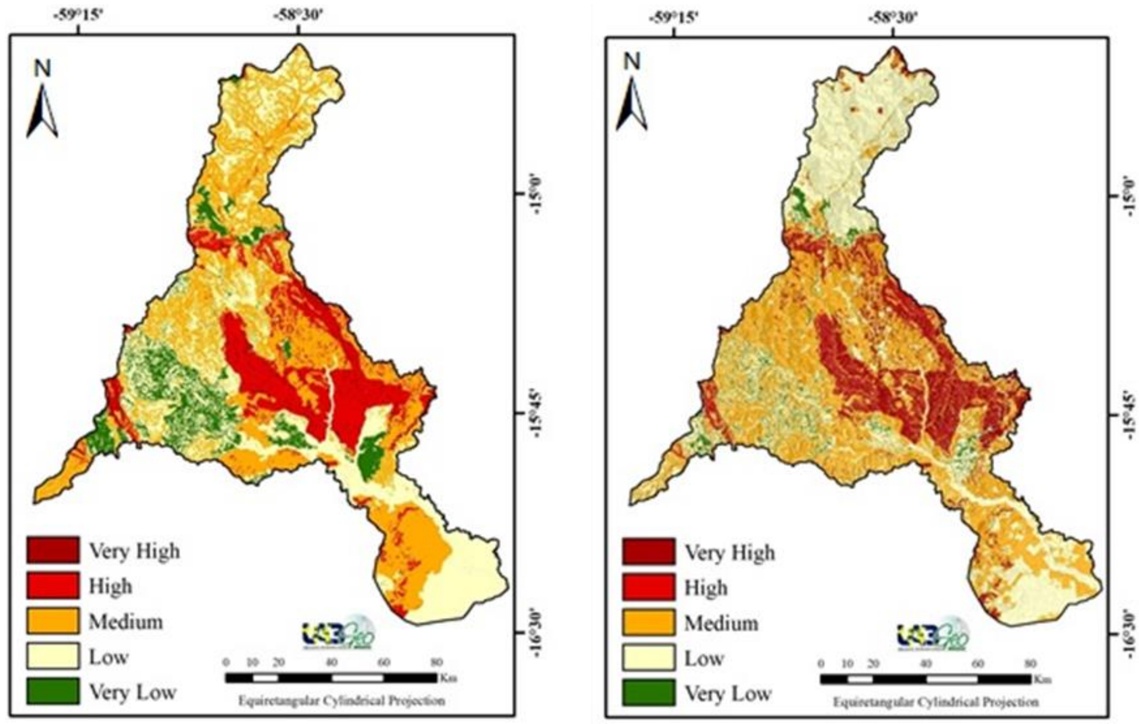

Figure 3 - (A) Natural vulnerability and (B) Environmental vulnerability of the Jauru River Hydrographic Basin – MT. Elaboration: The authors (2019).

As High and very high natural vulnerability areas totaled 23.31% of the study area (Figure 3A). In these areas, the direct influence of the marked slope (Undulated to Strongly undulated Reliefs) and lithological formations (Metovulcan-Sedimentary Jauru Plateau Sequence, Xingu Complex, Jauru Formation, Pantanal Formation, intrusive Guapé Suite, intrusive Rio Alegre Suite and Pulga Formation), presents convex forms in relation to geomorphology.

In pedological terms, the main limiting factor for the use of the abovementioned areas using high technology is the rugged relief that favors the accelerated surface runoff, resulting in soil and water loss, which is also a limitation to mechanization. In some cases, the use of terraces or permanent vegetation cordons is indicated.

Areas presenting very low natural vulnerability represent 8.66% of the basin's extent (Figure 3A), formed by the Xingu Complex, Pulga Formation and Intrusive Rio Alegre Suite, with red Argisols and plain to softly undulated reliefs. These areas are indicated for planted and forage pastures at level B and C on a regular basis and, in some places, restricted at level B and inapt at level C (Figure 4). These are promising areas for anthropogenic intervention, since their characteristics indicate lesser environmental risk situations, subject to limitations and relevant environmental legislation. However, considering the incorporation of these areas for agricultural use, the pertinent environmental legislation must be considered, the use of lesser impact technologies encouraged and the implementation of environmental control and monitoring plans should adopted, as well as compensatory measures and environmentally sound practices (ZANELLA *et al*., 2011).

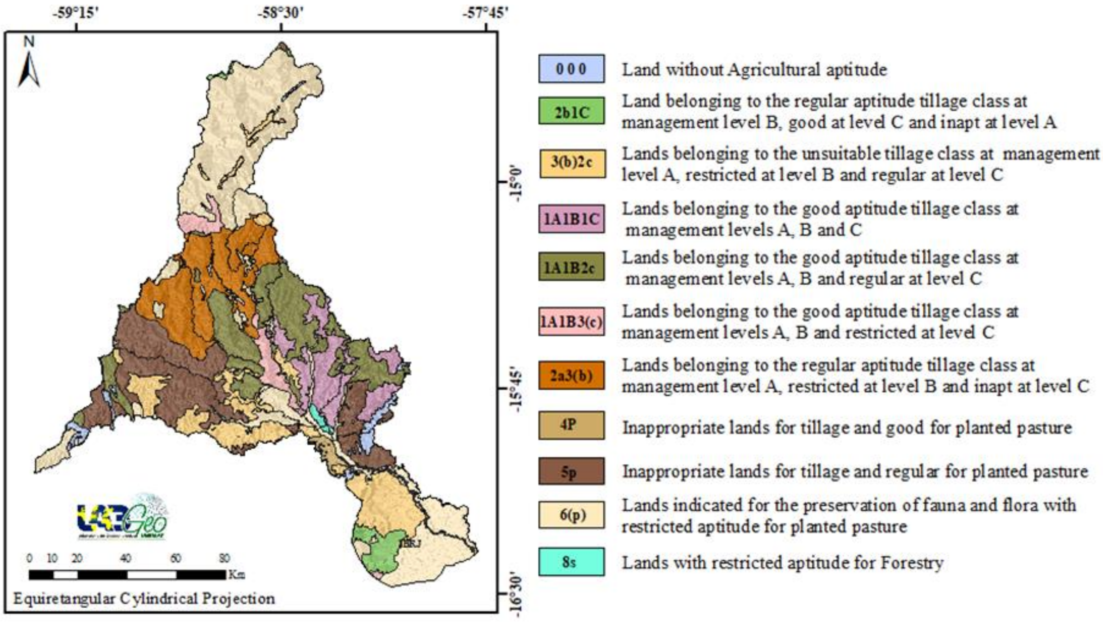

Figure 4 - Agricultural aptitude of the lands located in the Jauru River Hydrographic Basin - MT. Elaboration: The authors (2019).

The middle class prevails with regard to environmental vulnerability, which corresponds to 40.31% of the territorial extension of the assessed hydrographic unit (Figure 3B), comprising areas previously occupied by the Cerrado (Brazilian Savannah) plant formation, allowing for livestock expansion in plain to undulated relief areas.

Soil suitability ranged from 'good' for crops (1ABC) to 'without agricultural aptitude (000)', mostly indicated for planted pasture. However soil degradation is noted at the JRHB, due to inadequate pasture management (Figures 5 and 6).

Figure 5 - Area pasture suffering degradation in the municipality of Jauru– MT. Source: LabGeoUnemat (2017).

Figure 6 - Erosive processes in areas of FigueirópolisD'Oeste– MT. Source: LabGeoUnemat (2017).

Dias Filho (2011) reported that about 70 million pasture hectares in the Brazilian Midwest and Northern regions are degraded, or suffering degradation, i.e. unproductive pastures or those displaying very low productivity. According to Cardoso and Santos (2012), in order to obtain good results with extensive livestock pastures, they must be efficiently managed and used, adjusting the stocking rate of the herds to avoid over-grazing and to exclude excessive pasture trampling and degradation. These actions guarantee adequate plant cover, protecting and maintaining soil fertility. Moreira *et al*. (2005) point out that the continuous use of inadequate soil preparation equipment, the use of pastures made up of fertility-demanding forages in an extensive grazing regime, a lack of nutrient replenishment, soil acidification, loss of organic matter and soil compaction decreases pasture efficiency, leading to rapid soil degradation.

The low and very low environmental vulnerability classes accounted for 36.71% of the basin's extent (Figure 3B). These areas are mostly located in the southern portion, where a predominance of natural vegetation mainly due to soils unfit for agricultural activities is observed. They are also located in the southeast portion, where the Pantanal plain occurs (Figures 7 and 8).

Figure 7 - Native vegetation in the municipality of Tangará da Serra – MT. Source: LabGeoUnemat (2017).

Figure 8 - Pantaneira area in the municipality of Cáceres– MT. Source: LabGeoUnemat (2017).

Although presenting low vulnerability, these areas must adopt environmental control and monitoring measures. These actions are justified by the presence of QuartzeneicNeosols, which contain high sand content that disaggregates with greater ease, resulting in erosive processes (AZEVEDO and MONTEIRO, 2006). Freitas *et al*. (2015), when researching the Jauru-MT micro region, demonstrated that the vulnerability of these soils, when occupied without previous planning, can lead to areas susceptible to erosion and severe degradation processes, and are not recommended for agricultural purposes.

Vegetation maintenance, as well as the predominance of a plain relief, are essential to the maintenance of 'low' and 'very low environmental vulnerability'. Thus, the most stable areas are those with native vegetation, where the lowest vulnerability values were determined, indicating stability due to the slow surface flow that directly influences soil erosion capacity (LOPES and SALDANHA, 2016).

The 'high' and 'very high environmental vulnerability' classes predominated in the center-east portion (17.71%) of the studied territory (Figure 3B). The geological formation corresponded to the Jauru Plateau Metavulcano-Sedimentary Sequences, Pantanal Formation, Jauru Formation, Fortuna Formation/Vale da Promissão Formation, Utiariti Formation, Salto das Nuvens Formation, Araras Formation, Pulga Formation and the Xingu Complex, with reliefs varying from Plain to Strongly undulated. Suitability ranged from ‘good’ to ‘no agricultural aptitude’ for crops under all types of management (1ABC), and ‘restricted aptitude’ for planted pastures (6 (p)), designated exclusively for conservation. Currently, these areas are occupied by extensive livestock farming and agriculture and under urban influence.

Basic economic activities are important as an environment-transforming agent. The intensified increase in areas destined to agriculture and cattle ranching and the decreases in forest and Cerrado areas, in addition to reducing the basin's fauna and flora, can lead to serious consequences for the rivers in the region. Cemim*et al*. (2009) restate that the conversion of natural vegetation, the result of human action, to land cultivation, road construction and the creation and expansion of urban centers, has led to a marked change in the natural landscape, often reaching areas of great environmental sensitivity.

Finally, it is understood that an organized public power and society are essential concerning rural economic activities in the assessed basin, aiming at economic development alongside conservation, aiming at the minimization of environmental damage. In order to do so, planning must consider environmental potentialities and vulnerabilities, allowing land use by adapting lands to soil and water conservation.

4 CONCLUSIONS

Jauru River Hydrographic Basin areas covered by natural vegetation and/or pastures present medium natural vulnerability and medium to high environmental vulnerability, evidencing that livestock farming, the main economic activity carried out in the region, has developed in disagreement with environmental suitability, contributing to increased environmental vulnerability in the basin.

Data on natural and environmental vulnerabilities in the basin's territorial reorganization of the should be incorporated, in order to minimize impacts resulting from economic activities, especially those not in line with environmental capacities of the Pantanal biome hydrological cycle.

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