RESEARCH PAPER

CAPACITY AND CURRENT USE OF THE FORMOSO RIVER WATERSHED, BONITO MUNICIPALITY, MATO GROSSO DO SUL, BRAZIL: CONFLICTS AND LAND USE RECOMMENDATIONS

Rafael Brugnolli Medeiros[1*], Charlei Aparecido da Silva[1]
[1] Federal University of Grande Dourados/Faculdade de Ciências Humanas, Rodovia Dourados/Itahum, Km 12, Cidade Universitária, Dourados/MS, 79.804-970, Brazil
***Corresponding author:** rafaelmedeiros@ufgd.edu.br
Received: December 18th 2023 / Accepted: September 1st 2024 / Published: October 1st 2024
https://doi.org/10.24057/2071-9388-2024-3159

ABSTRACT. The lack of planning and feasibility of controlling actions over land use and land cover lead to relationship problems between the support capacity that environmental systems present and their current use. The goal of this study is to figure out how much land can be used based on its natural and physical features and to find problems that come up because of the heavy use in the Formoso River watershed. It is one of the most recognized Brazilian watersheds, due to its turistic, karst, and environmental characteristics. The methodology consists in handling and generating data in a GIS environment by performing a synthesis map, as well as adopting geoprocessing criteria and techniques in the field to validate the collected data. The results indicate that the watershed presents large areas without conflicts due to its numerous conservation units. However, major conflicts are identified in other areas, affecting the balance and dynamics of the landscape and its water resources. Such conflicts arise because soybean crops advance in fragile and karst areas. The highest concentration of confit is only 1.61%, particularly near the Formoso River marsh. Therefore, the present work considers a methodology that assesses the capacity of use through a method that has produced a summary document that is applicable and compatible with the karst system

KEYWORDS: karst system, water resources, land use, geoprocessing,environmental fragility

CITATION: Brugnolli R. M., Silva C. A. da (2024). Capacity And Current Use Of The Formoso River Watershed, Bonito Municipality, Mato Grosso Do Sul, Brazil: Conflicts And Land Use Recommendations. Geography, Environment, Sustainability, 3(17), 85-97
https://doi.org/10.24057/2071-9388-2024-3159

ACKNOWLEDGEMENTS: This study was conducted thanks to the support of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—CAPES and the Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul—FUNDECT. The project was developed at the Federal University of Grande Dourados, where the Physical Geography Laboratory - LGF (www.lgf-neef.com) provides the physical and software support required to conduct this research.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Karst systems offer considerable potential for various uses and activities, including limestone mining, tourism, and monoculture agriculture. This is due to the presence of carbonate rocks, which create fertile soils and relatively flat landscapes. Karst's potential for such activities is undeniable, but their use can trigger impacts and processes that lead to environmental damage. In short, medium, and long terms, significant damages occur, such as sinkholes and landslides caused by rocks depleted by the karst process, contamination of aquifers (Tavares; Vieira and Uagoda 2023), degradation of speleological assets, and impacts on the quality of surface waters. The karst is affected in a big way when its weaknesses are ignored in order to support the development bias of public and private bodies and documents (like ecological-economic zoning and master plans). Van Beynen, Brinkmann and Van Beynen (2012) highlight the mining activity as the cause for karst damage, whereas Ford and Williams (2007) and Silva and Morais (2011) indicate that monoculture is an activity that stands out in terms of causing karst implications, contributing to losses in this type of landscape. In both economic activities, sediments and residues transported by rainwater generate impacts that are often irreversible in a karst system. Parise, De Waele and Gutierrez (2009) and Parise (2012) state that the process of transporting sediments from agriculture and mining causes changes in groundwater flow and the quality of surface waters. Therefore, the environmental impacts arising from anthropic actions occur due to the lack of knowledge and comprehension on the relevance of land use, land cover, and the vegetative canopy that covers the soil in these environments. We highlight here anthropic actions, such as degradation of slopes and valleys, the obliteration of sinkholes, pollution of reservoirs and karst aquifers, the constant use of aquifers for irrigation, and its consequent loss of natural replenishment capacity (Burri et al. 1999). All forms of occupation in a karst watershed must consider its capacity of use in order to cause minimum conflicts with regard to its current use. Lepsch et al. (1991) define capacity of use as possibilities and limitations of use, suitable or not for certain purposes according to the physical environment conditions. Leal (1995) defines capacity as the type of use exercised in a given landscape unit without causing environmental changes or modifying the intrinsic dynamics of the units.

According to Ochieng Odhiambo (2000), Castro and Nielsen (2001) and Hilson (2002) conflicts over natural resources are concerning and debilitating; environmental degradation affects the entire society. The dynamics of land use and land cover are critical watershed management issues, yet the cumulative impacts of these changes are difficult to discern and manage in the typical practice of land use planning (Erickson 1995). Therefore, evaluating the current use and occupation is essential for the territorial and environmental management of watersheds. In addition to providing subsidies for urban and regional planning, it enables a rational relationship between the anthropic advance of land and natural resources (Wilson 2014). The fact that this relationship may be analyzed on a local and regional scale and on a temporal scale brings up the possibility of becoming an environmental monitoring instrument (Angel et al. 2005; Cohen 2006). Suitable forms of land use and land cover for environmental purposes become effective since the existing interactions between the components of the landscape are evaluated, their weaknesses and potentialities, as well as the internal and external influences that affect the system. Thus, negative impacts of use are minimized.

Identifying such contexts in the region of Bonito is a challenge due to the imminent use of its lands for soybean monoculture, which causes recurrent clouding of scenic rivers (Ribeiro 2018; Brugnolli et al. 2022), and damages to its fragile and still preserved karst features. Boggiani et al. (2002) and Sallun Filho, Karmann and Boggiani (2004) point out that the karst characteristics in Bonito, more precisely on Serra da Bodoquena, bring several environmental concerns due to the rapid occupation of the area. The process increases the removal of forest vegetation to allow monocultures and pastures to enter. The mountain karst and its surroundings are extremely vulnerable, and their use requires restrictions. Therefore, the assessment of the system's capacity for use and actual use contributes to watershed management. The present work adopted the Formoso River Watershed as its study area because it is the largest and most significant watershed in Bonito; it has a municipal dimension but is of global relevance, given its potential and recognition as a tourist destination. Large extensions of native forests (Serra da Bodoquena) and soybean crops can be seen in the upper and mid-course of the river. The way land has been used without adequate management, added to other existing anthropic activities, such as cattle confinement areas, limestone extraction, extensive livestock, and tourism, leads to environmental disturbances. In addition, it generates pressure on surface waters that depend directly on the conservation and maintenance of the watershed balance. Evaluating the support capacity brings a technical document with data to assist in a balanced use that may be a conditioning factor for planning and managing the development on a sustainable basis (Narendra et al. 2021). Although seeking the balance between anthropic actions and the environment is complex, the performance of documents like the one proposed by this work may guide actions and recommendations to reconcile the needs of society with the territory capacity of support.

In addition, some areas have high erosive potential due to their steep slopes. Brugnolli (2023) describes methodologies that assess this potential by analyzing slope, horizontal, and vertical dissection to gauge the likelihood of morphogenetic processes occurring. This approach generates a document that summarizes the terrain's characteristics. The analysis is based on General Systems Theory, which focuses on understanding the interconnected and systemic relationships between different elements. Recognizing that vegetation is essential for minimizing erosion potential, it is concerning that there is little native vegetation outside conservation units. Much of the land not designated for primary vegetation has already lost its ecological balance and is moving towards critical levels of degradation.

It is relevant to highlight the lack of studies and federal, state, and local laws that take karst and its unique dynamics into account. Thus, such a diagnosis in the municipality of Bonito, precisely in the Formoso River Watershed, was carried out aiming to assess the capacity of use and its real use, identifying land use conflicts by following a congruence between capacity, environmental fragility, and the current intensity of use. The Formoso River Watershed (FRW) is located southwest of the state of Mato Grosso do Sul (Fig. 1), in an area of 1,324.67 km^2. Its spring is located in the Serra da Bodoquena, while its mouth is located mid-course on the left bank of the Miranda River.

Materials and Methods

The methodology consists of investigating the components of the landscape, identifying the capacity of use, current use, and the conflicts involved in this relationship. The starting point was the lithology of rocks that was carried out with the support of GIS ArcGis 10® using the geological map provided by the Geological Survey of Brazil (Serviço Geológico do Brasil – SGB). A more detailed study was performed using satellite images and field trips to visualize the outcrops and handle rocks along local highways, banks of water sources, and in the midst of pastures and vegetation throughout the Formoso River Watershed. The rainfall was linked to the mapping carried out by Zavattini (1992), which discusses the distribution of precipitation with a climatic regionalization due to the influences of air masses and rainfall in the state of Mato Grosso do Sul. For the relief, we carried out slope and erosive potential energy analysis of the relief, following the methodologies of Brugnolli (2020) and Brugnolli (2024). For the slope analysis, we imported the Digital Elevation Model (DEM/SRTM) based on the classes of the Brazilian Soil Classification System (Sistema Brasileiro de Classificação de Solos – SIBCS 2018), Lepsch et al. (1991) and Ramalho Filho and Beek (1995) for the relief classifications and their facilities, and land use limitations. The erosive potential energy of the relief is defined as the potential erosion capacity or the amount of soil loss that the watershed is capable of promoting. We identified horizontal and vertical dissections with declivity in agreement with a synthesis product described by Mendes (1993) and Brugnolli, Berezuk and Silva (2019). The procedure consists of data interpolation in GIS ArcGis10®, in the *Spatial Analyst Tools > Overlay > Weighted Overlay module*. The module proposes

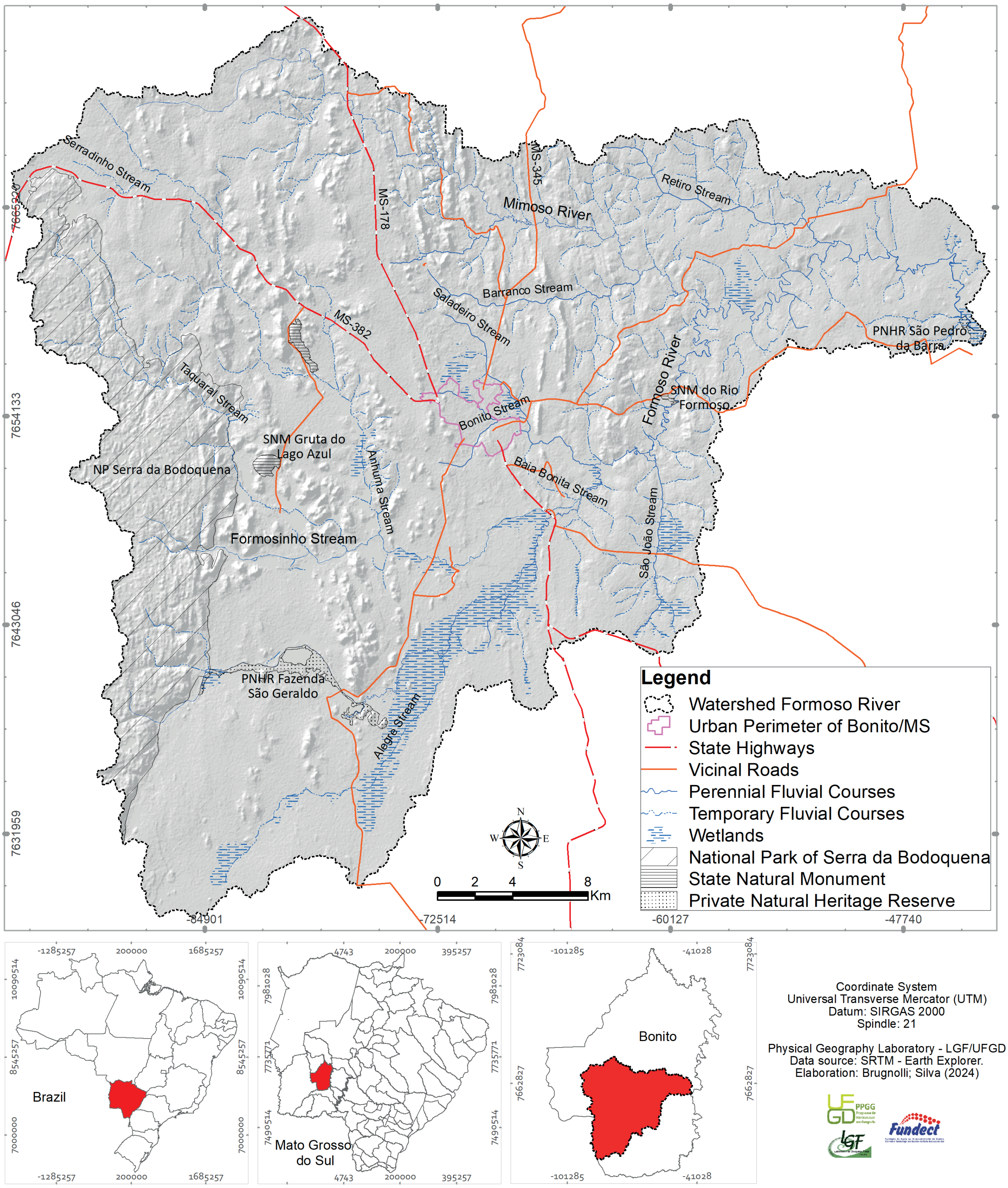


Fig. 1. Location of the Formoso River Watershed, Bonito/MS

the interaction of data equally through the weights inserted in each variable. The horizontal and vertical dissections result from the delimitation of all sub-basins and micro-basins supported by the SRTM/DEM (Shuttle Radar Topography Mission/Digital Elevation Model) methodology. The contour lines and the delimitations of the basins of ephemeral, intermittent, and perennial water resources were traced. Thus, a horizontal line was defined in straight lines, which form a 90º angle between the thalweg and the interfluve. The distance corresponds to the terrain slopes in meters (length). In addition, vertical lines are traced for each thalweg until reaching the ridge lines (interfluve), and each of these classes corresponds to vertical intervals in meters (amplitude). The Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA) provided data on the soils, and a pedological detailing with the reality of the land was done. The pedological detailing with the terrestrial reality was required once conflicts in the spatialization of soils in some locations were identified during our field work. Then, some corrections were defined in the initial mapping aided by satellite images. The detailing was supported by the Brazilian System of Soil Classification (Sistema Brasileiro de Classificação de Solos – SIBCS 2018). In mapping land use and land cover, we used GIS Spring 5.2.7 to handle and process CBERS 4A (China–Brazil Earth

Resources Satellite) program satellite images from the year 2023, which underwent supervised classification with 99% accuracy. The method used in this research was unsupervised in GIS Spring 5.2.7, creating a categorization by the histogram classifier. The categorization focuses on differentiating different themes through a region clustering algorithm, which uses a method that computes the distinction between histograms. The method abstracts nearby themes (each theme presents a behavior of targets), according to their spectral signatures. Therefore, we selected fifty themes aiming to provide relevant detailing, reduce conflict between themes, and assist in the final classification and visualization. Eventually, we carried out the reclassification to adjust the classes in each region and change those that presented variations in the spectral signatures, textures, patterns, geometry, and location of the surface targets. The adjustment occurred during field trips to investigate.

Using the data, we investigated the environmental fragility resulting from the interaction of physical environment and anthropic use, providing significant results that pionted out the most fragile locations in the face of erosional processes. The weights were defined according to the degree of environmental fragility represented by the classes, very low (1), low (2), medium (3), high (4), and very high (5). Therefore, when working with the aforementioned components, criteria previously established were adopted to search for a satisfactory index that shows the environmental fragility of the components.

Regarding the rocks, we studied the geological time, fragility, and degree of cohesion of the rocks to morphogenesis and their mineralogical compositions. The precipitation analysis followed the rainfall indices of Zavattini (1992). Although Latin American countries are known for their high spatial variability in rainfall, the unique rainfall values in the Formoso River basin are attributed to its location within the same Zavattini zone. At this scale of analysis, the landscape remains relatively unchanged, and rainfall variations are minimal. In the erosive potential energy of the relief, issues related to the inclination of the slopes (declivity), their length (horizontal dissection), and the amplitude (vertical dissection) were worked. In soils, issues such as porosity, texture, depth, and maturity were observed. In terms of land use and land cover, we evaluated the size of vegetation cover, soil protection, and vegetation density.

The last stage of the methodology focused on providing significant data about existing land use conflicts. Such conflicts were identified in the relationship between the ability to use the land through the physical components, and its current use. Thus, we need to understand whether it may cause environmental impacts and whether it interferes with the resources of the Formoso River Watershed. Therefore, methods and criteria were applied to define the indices and intervals established in each class. Relevant characteristics were identified (Fig. 2) making evident the relationship between the index intervals and the characteristics of the study area.

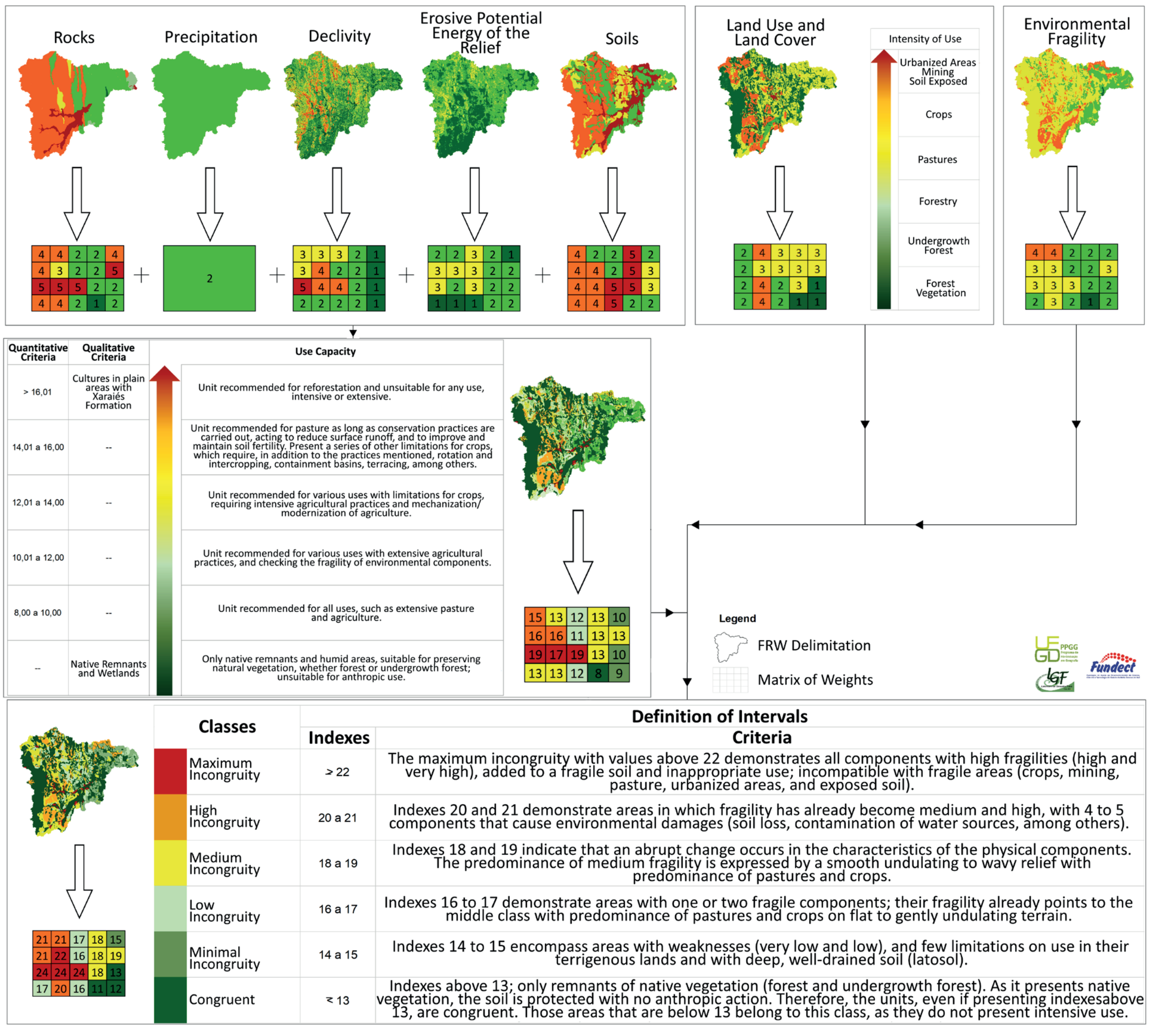


Fig. 2. Methodology for defining classes of land use conflict in the Formoso River Watershed, Bonito/MS

It is important to note that the intervals were established based on terrestrial validation, field visits, and the researchers' expertise in the subject and study area. After defining these intervals, the landscape elements within each were reviewed and adjusted as needed, drawing on the work of Lepsch et al. (1991), Dibieso (2013), Brugnolli (2020), and Brugnolli et al. (2022). The weights used are the same as those established in the analysis of environmental fragility, in which several tests were carried out using the averages. However, the method that brought greater veracity according to the physical components and their relationships with current use and terrestrial reality was the Weighted Sum Module (WSM) inserted in the ArcGis 10® GIS. Thus, the interpretation of these relationships, the empirical knowledge of the research area, and the environmental components addressed congruence classes, highlighting the conflict between capacity and current use. The classes were defined as congruent, minimal incongruity, low incongruity, medium incongruity, high incongruity, and maximum incongruity.

Results and Discussions: conflicts between land use capacity and the current use of the Formoso River Watershed

Working with the relationship between potential use (Fig. 3), (capacity of use through its physical components) and actual land use (current anthropic use), we present an analysis of existing conflicts and potential adaptation strategies. Several studies identify the capacity of use, such as Lepsch et al. (1991), Fernandes et al. (2010), Silveira et al. (2013), Silva et al. (2013), among others. The preceding authors worked with the determination of land use capacity subclasses, seeking land use planning and practices of soil conservation. According to Dibieso (2013, p. 230), the capacity is expressed by "susceptibility to the development of erosive processes and pollution of waters". The aim is to support decision-making, organize the use of land according to its capacity, and, therefore, reduce the development of erosion, increase productivity, and mitigate environmental damages.

By contextualizing the classes of capacity of use and correlating them with their intensity, Dibieso (2013) highlights that it seeks to draw a parallel between the physical environment and its current use, identify conflicts, and define levels for such conflicts. As a result, the adjustments between the current use and the dynamics of the study unit were characterized as compatible or congruent, as described in this research. They concern a conformity between the weaknesses and potentialities of the components (rock, climate, relief, and soils), and current use. Therefore, an intimate relationship is identified between the incongruities in land use and environmental disturbances in watersheds. Even if not currently visible, in the medium and long term, the susceptibility to the occurrence of environmental damages will be undeniable. Given the incongruities identified in the process of analysis, the conservation practices adopted must be according to the levels of these incongruities. The levels of incongruity were verified based on the specificities of environmental fragility, fragility of rocks, soils, climate, relief, and land use. The methodology applied revealed variations in the levels of incongruity in the relationship between capacity and current use. The levels vary according to their potential and the intensity of current land use. The variation goes from a congruent relationship (when the use is within what is compatible), to the levels of minimal, low, medium, high, and maximum incongruity (Fig. 4).

The existence of few karst areas in Brazil means that these regions host endemic species. As monocultures advance, they fragment habitats, pollute, and contaminate both surface and groundwater. Monocultures typically deplete soil nutrients, increasing dependence on agrochemicals, and often result in the deforestation of forests and other natural habitats. This hinders the survival of many species and reduces regional biodiversity (D'Ettorre, Liso and Parise 2024). Thus, we identified a relationship between conflicts with their (in)congruences and the environmental disturbances that occur in a watershed. However, according to Dibieso (2012), a unit may exhibit high incompatibility, even presenting techniques for mitigating possible disturbances that favor the maintenance of current use. On the other hand, a unit may present low incompatibility, but given specific characteristics and inefficiency of conservation practices, it can lead to serious environmental disturbances (Fig. 5).

Identifying conflicts in the relationship between capacity of use versus current use aims to promote preservation, conservation, and recovery. The focus is on fragile areas, areas of native vegetation still intact, alluvial plains, the Formoso River wetland (refuge of biodiversity, which acts as a sediment filter for the waters of the upper course of the watershed), steep slopes with strong relief energy, among other sectors that require conservation to maintain the ecological balance and water resources, reducing the occurrence of damaging environmental impacts in the Formoso River Watershed. Based on this premise the analysis of conflicts started with the Maximum Incongruence class, characterized by high and very high fragility, mainly formed by carbonate rocks and fragile soils, such as gleisols, chernosols, and neosols. The regions represent 21.39 km² or 1.61% of the watershed, which is a rlatively small area compared to the overall scope of the watershed. However, the regions require attention due to the inappropriate use associated with high fragility. The use of these lands varies from crops, pastures, and urbanized areas to exposed soil and mining, presenting intensive use capable of causing environmental damages. The regions demand concern due to the rocky substrate formed by limestone tufas and travertines (Xaraiés Formation), as well as carbonate rocks (Cerradinho and Bocaina Formations). In the first case, they present recent river deposits, naturally eroded and extremely fragile. In the second case, the fragility occurs due to the chemical dissolution capacity of limestone in relation to the percolation of water in rock cracks, which may result in disruptions. Moreover, they are located close to native forests in the upper course of the Mimoso River, in the alluvial plain of the upper and middle course of the Formoso River, sub-basin of the Córrego Alegre (upper course), and close to the Formoso River wetland. The Formoso River wetland suffers significant environmental damage from intensive use in karst and fragile alluvial plains. The analysis identified risk areas related to the slope and type of land use. Fig. 6(A) represents an area of exposed soil and the beginning of a steep slope. Additionally, the soils in the location favor their high fragility (shallow and stony). Given the characteristics, we highlight the presence of the Bonito-controlled landfill, which reinforces its classification and incongruity. Fig. 6(B and C) shows the loss of soil due to linear ravinement erosion. It is a fragile area due to its high slope (varies in slopes greater than 45%, which by law are Permanent Preservation Areas - PPAs), and lack of major vegetation to protect the soil. These sectors and their current conditions characterize them as maximum incongruity, due to the residual hills taken over by pastures and the absence of land management to contain or eliminate erosion.

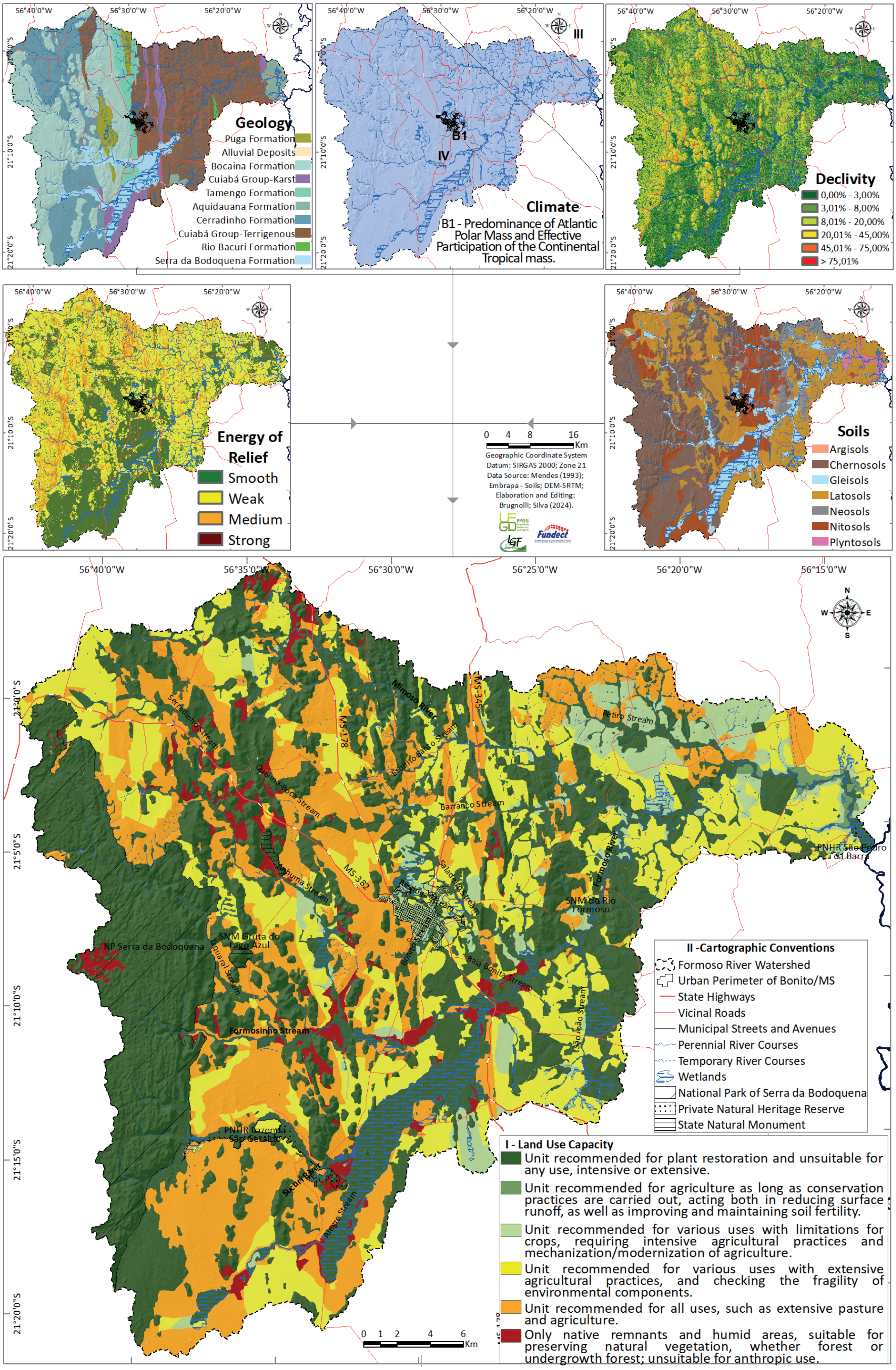


Fig. 3. Land Use Capacity of the Formoso River Watershed, Bonito/MS

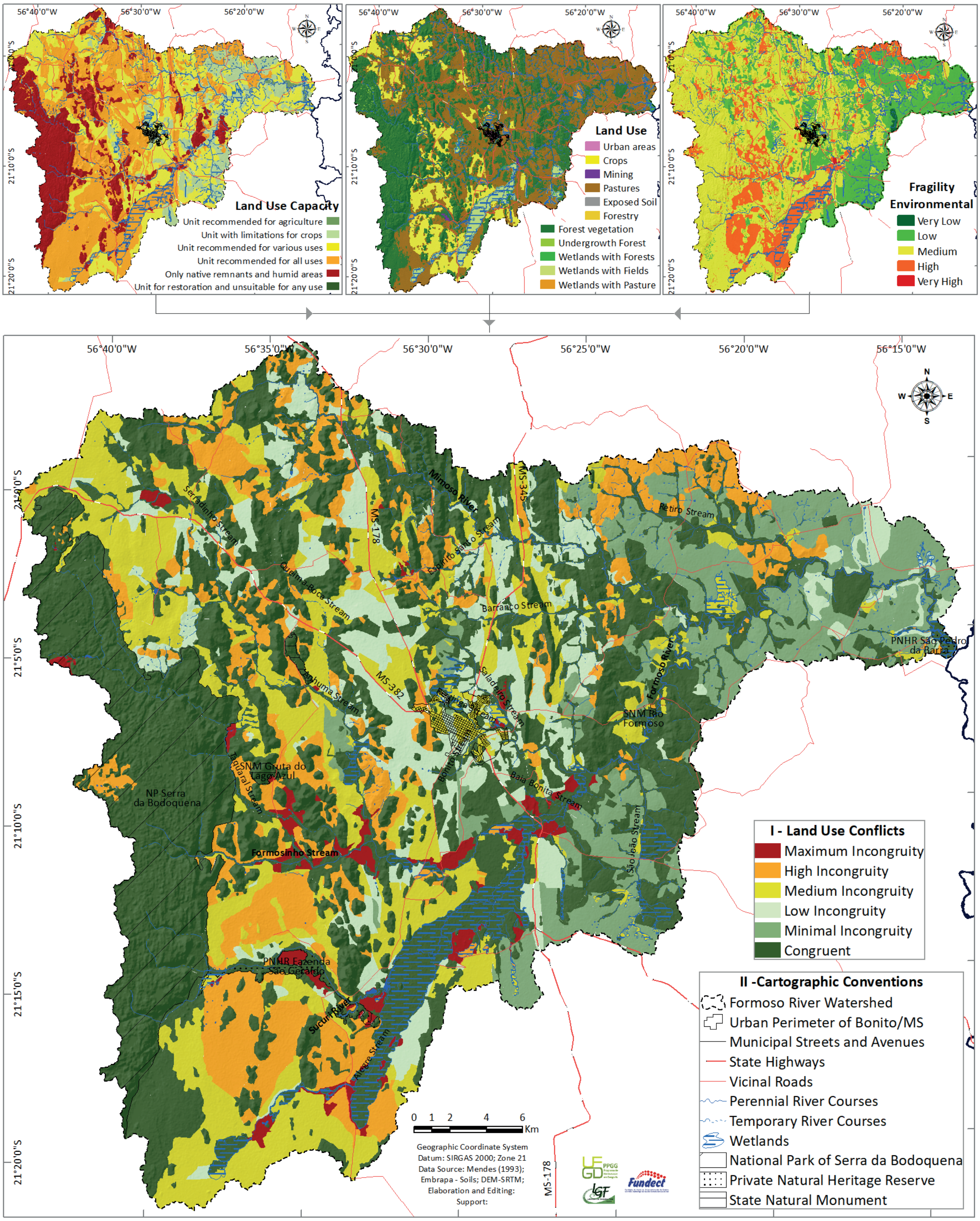
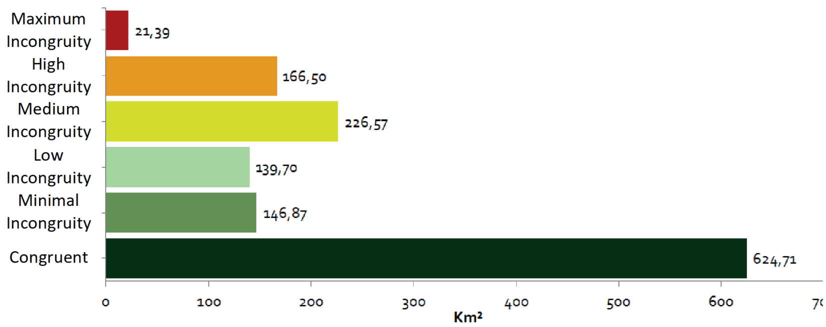


Fig. 4. Land Use Conflicts in the Formoso River Watershed, Bonito/MS

I – Conflicts of Use and Land Cover	Description of Classes	Iconographic points
Maximum Incongruity Coverage Area Km² % 21,39 1,61	Areas with Maximum Incongruity present high and very high fragility, represented by carbonate rocks, slopes and fragile soils, such as gleisols, chernosols, and neosols. Its use is varied with crops, pastures, urbanized areas, exposed soil, and mining. The class is suitable for reforestation and unsuitable for pastures and crops.	 
High Incongruity Coverage Area Km² % 163,42 12,33	Areas with High Incongruity present medium and high weaknesses, being the class that present high variety in its characteristics; present flattened or highly undulating relief formed by neosols, chernosols, gleisols, or nitisols, superimposed on terrigenous and karst terrain with pastures, crops, and urbanized areas. The class presents severe restrictions, and the use of pastures is recommended with restrictions, as long as conservation practices are carried out, acting to reduce surface runoff, and to improve and maintain soil fertility. They present a series of limitations for crops, requiring, in addition to the practices mentioned, rotation and	 
Medium Incongruity Coverage Area Km² % 229,23 17,29	Areas with Medium Incongruity present medium weaknesses expressed by a smooth undulating to undulating relief, with varied soils and rocks. Pastures and crops predominate the areas. The class is recommended for various uses, however, with limitations for crops, requiring intensive agricultural practices and mechanization/modernization of agriculture.	 
Low Incongruity Coverage Area Km² % 140,20 10,57	Areas with Low Incongruity present medium fragility, varied rocks and soils, however, pastures and crops predominate the flat to gently undulating terrain. The unit is recommended for various uses, using extensive agricultural practices, checking the fragility of environmental components.	 
Minimal Incongruity Coverage Area Km² % 146,87 11,08	The class with Minimum Incongruity presents low fragility, and its lands are overlaid on terrigenous rocks with predominance of latosols. Crops (soy, corn, and forestry) and pastures predominate the area. The low fragility favored the high capacity of use of the lands. Recommended for all uses, such as extensive pasture and agriculture.	 
Congruent Coverage Area Km² % 624,63 47,12	The Congruent class is related to all forest remnants, even if it is highly fragile and, consequently, presents low capacity of use. As long as it presents native vegetation (forest or undergrowth forest), it becomes compatible, as native vegetation protects the soil, leaving it covered against rainfall and anthropic action. The class is suitable only for preservation, being unsuitable for anthropic use.	 



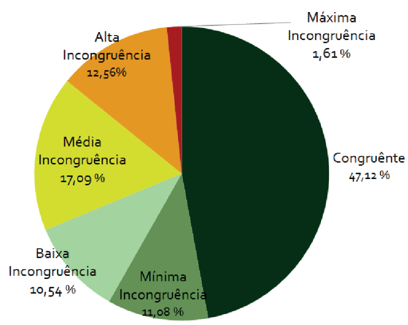


Fig. 5. Land Use Conflicts of the Formoso River Watershed, Bonito/MS, with their respective descriptions and representative points

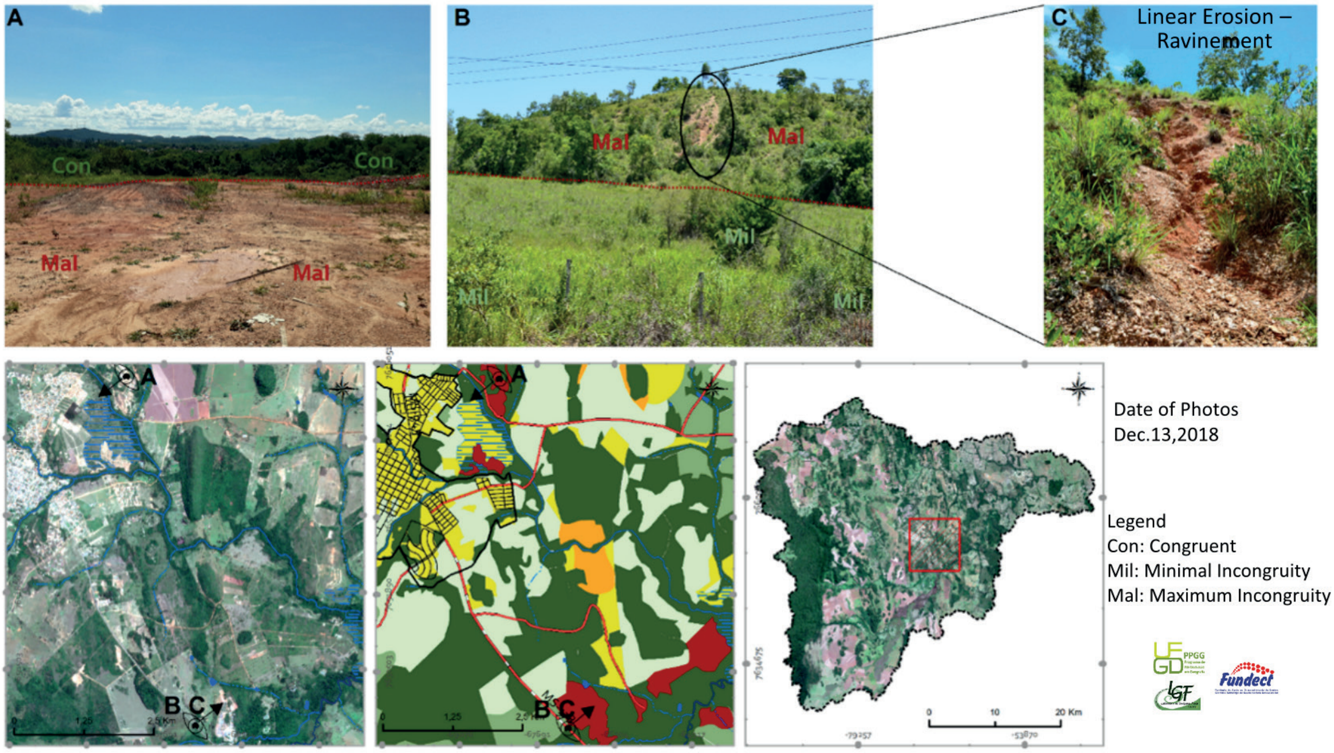


Fig. 6. Controlled landfill in areas of maximum incongruity (A), and linear erosion triggered by poor land use (B, C), in the mid-course of the Formoso River Watershed

Thus, all these regions present themselves suitable for the re-establishment of forest vegetation, as they are not suitable for pasture and/or crops due to their fragility. The inadequate use of soil, added to its greater exposure (exposed soil), makes these places susceptible to erosion, whether due to the dragging of soil particles by rainwater as well as the coarse texture of soils (neosol). Plant restoration is recommended for soil maintenance and protection, benefiting the development of native species of fauna and flora in the vicinity of the Formoso River wetland. In this matter, the aim is to increase the water infiltration capacity in the soil and reduce erosion processes and river damming (an increasingly recurrent problem in the watershed). Lepsch et al. (1991) highlight the issues, stating that the areas are subject to permanent limitations, unsuitable for crops, and restricted to pasture. Plant restoration with appropriate care is required, as it may be susceptible to damage. The definition of the incongruity classes that indicated the limitations determined the frequent environmental changes and how limitations are sustained by the capacity of use. The areas with high incongruity are located throughout the entire Formoso River Watershed, mainly in the upper and middle courses, where carbonate rocks, i.e., karst environments, are prominent. Thus, we studied its characteristics and weaknesses, pastures, and crops as its main uses. The study performed field activities and used satellite images to define the demand for conservation practices. Practices that may aid in reducing sediment carryover and the control of various linear and laminar erosions, adequate management, soil preparation, and planting of forage vegetation in pastures. Yet, a large part of pastures is compacted, due to cattle trampling and the absence of land management. The high incongruity class covers a total area of 163.42 km^2, or 12.33%. It presents significant extension and denotes reliefs ranging from flat to strongly undulating, formed by neosols, chernosols, gleisols, or nitisols, overlapping in terrigenous and karst terrains. In addition to the exposed weaknesses inherent to the physical components of the watershed, the presence of cattle was identified, making them prone to the development of erosive processes. Thus, the implementation of fences may prevent animals from entering these regions, as illustrated in Fig. 7.

The slope alone does not determine a legal need for plant restoration or vegetation preservation. However, the other components increase the fragility of the areas, compromising the capacity of use (whether for the rocks of the Tamengo Formation with calcitic limestones, which present high fragility, or due to the average relief energy and its fragile soils, such as chernosol and gleisol). Such factors determine the high fragility in the aforementioned areas of the Formoso River Watershed, where the land used for pasture has brought high incongruity. However, by applying a set of intensive conservation practices that act in reducing surface runoff and improving and maintaining soil fertility, the areas may become suitable for such uses. As for crops, a series of other restrictions are exhibited, requiring the practices mentioned as well as crop rotation, especially in fragile soils and steep relief, terracing, and containment basins with the purpose of dissipating sediment transport. In Fig. 7 (B, C), the slope varies from 0% to 8% (foreground), and may reach up to 45% (background). The sector shows erosion due to rainfall and lack of vegetation. The sector demands actions to recover the local vegetation cover and/or erosion containment. Such actions may occur through the application of techniques, such as the creation of contour lines and/or containment basins to contain the advancement of soil loss, since no type of land management is indicated in the area. The analyses show that areas with maximum incongruity and high incongruity present a high risk of erosion due to the high fragility of the lands, in addition to the steep slope that favors surface runoff. In smaller proportions, the medium incongruity class portrays varied characteristics of the physical environment; however, when unified, it brings certain weaknesses to the system. The areas are spread over 229.23 km^2 or 17.29% of the total area, identified in all regions of the Formoso River Watershed, especially in the upper and middle courses, in gently undulating to undulating locations, and soils that present good drainage, such as latosol and nitisol. The

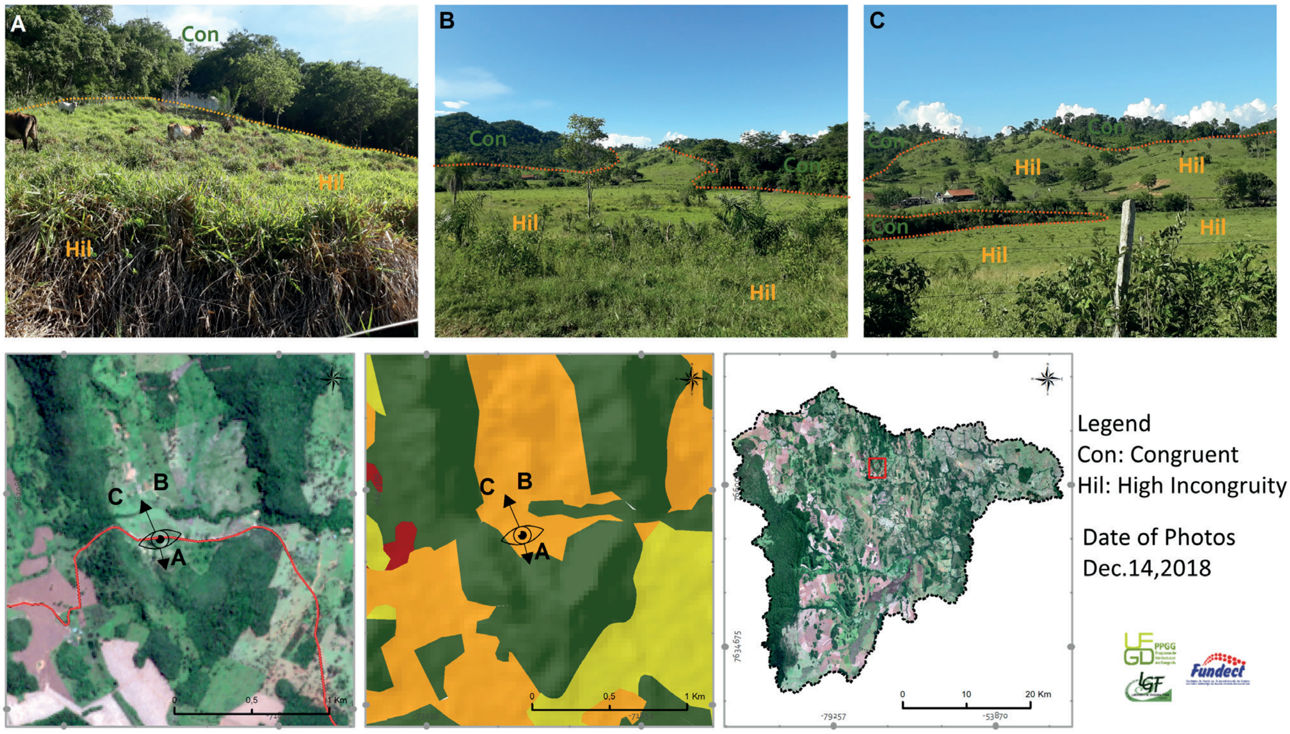


Fig. 7. Cattle grazing in steep areas (A) with pastures on the hills where erosion processes are observed (B and C), in the middle course of the Formoso River Watershed

average incongruity reveals factors that make it susceptible to erosion, such as pastures and crops in karst areas. The sector requires significant care and maintenance, due to the high degree of dissolution and risk of disruptions. The units are suitable for various uses, but with limitations for crops, as they require intensive agricultural practices and mechanization/modernization of agriculture. However, as it already represents an intermediate class of incompatibility, conservation practices are required, such as terracing on steep slopes, contour lines in all crops and pastures, and retention boxes on roads. The practice prevents the effect of erosive potential energy of the relief highlighted, in some areas, for medium to mildly strong classes, during soybean harvest. The harvest period leaves the soil exposed to more intense precipitation, the main cause for "river damming". Areas of low incongruity face small conflicts, that is, regions where land uses partially correspond to their capacity of use. The class is spread over 140.20 km^2 or 10.57% of the total watershed, predominantly located in the mid- and lower courses of the watershed. The low incongruity class exhibited a variety of characteristics, always pointing to low and medium weaknesses. The pedogenetic realities aids to reduce erosion, as this class (low incongruity) is located in terrains of latosols, nitosols, and plinthosols that present good to medium drainage, deep/evolved, and medium to sandy texture. Even with improvements in soils capacity, the class deserves concern because pastures and/or crops predominate its lands. Despite being units recommended for various uses, they require extensive agricultural practices to verify the fragility of environmental components. The sectors with minimal incongruity are spread over 146.87 km^2 or 11.08%, and show unique characteristics. One concerning characteristic is that all uses are located on a substrate of terrigenous rocks of the Puga and Cuiabá Group Formations (Psammitic, Pelitic, and Conglomeratic) showing low fragility. Moreover, the soils formed by nitosols, plinthosols, and latosols favor improvement in the land capacity of use as well as reducing surface runoff, as they present good to medium drainage. Thus, these units are suitable for all uses, such as extensive pasture and agriculture, as long as they meet the capacity/restrictions expressed in the environmental components. The units require simple conservation practices, such as alternation of paddocks for livestock and contour lines. According to Lepsch et al. (1991), areas that present minimal use limitations may be used for annual and perennial crops, pastures, and/or plant restoration, as they pose few environmental disturbs and require common practices to improve and maintain soil fertility and crop rotation. Thus, we highlight that even the sectors with minimal incongruity may present risks for erosive processes, as they depend on the way in which pasture management is carried out (137.87 km^2 or 91.09% of the total for the class), crops (8.93 km^2 or 6.08%), and forestry (0.07 km^2 or 0.05%). As a result, the minimum incongruity class still receives special attention in the Formoso River Watershed, focusing on the management employed rather than the capacity of use. In the sectors of minimum incongruity, a great part of pastures in the lower course of the river present an absence of land management. It becomes a motivating differential for the development of erosion processes, as well as for the development of environmental damages related to poorly planned dams, and the current situation of local roads (extensive erosion) (Fig. 8).

The congruent class does not present conflicts between capacity and current use. It concerns all forest remnants, even if the class presents high fragility and, consequently, low capacity of use. Whem native vegetation occurs, it becomes congruent/compatible, protecting the soil against rainfall and anthropic actions. The class becomes unsuitable for anthropic use because it is only suitable for preservation, protection of wild fauna and flora, and water storage (dams and dams). According to Lepsch et al. (1991), the class is unsuitable for commercial forests, such as silviculture, or for the production of any other form of permanent vegetation with economic value. Furthermore, the preservation of vegetation maintains the hydrological cycle, thereby reducing erosion processes.. It allows water to infiltrate the soil and supplies the Formoso River wetland, being essential during periods of drought.

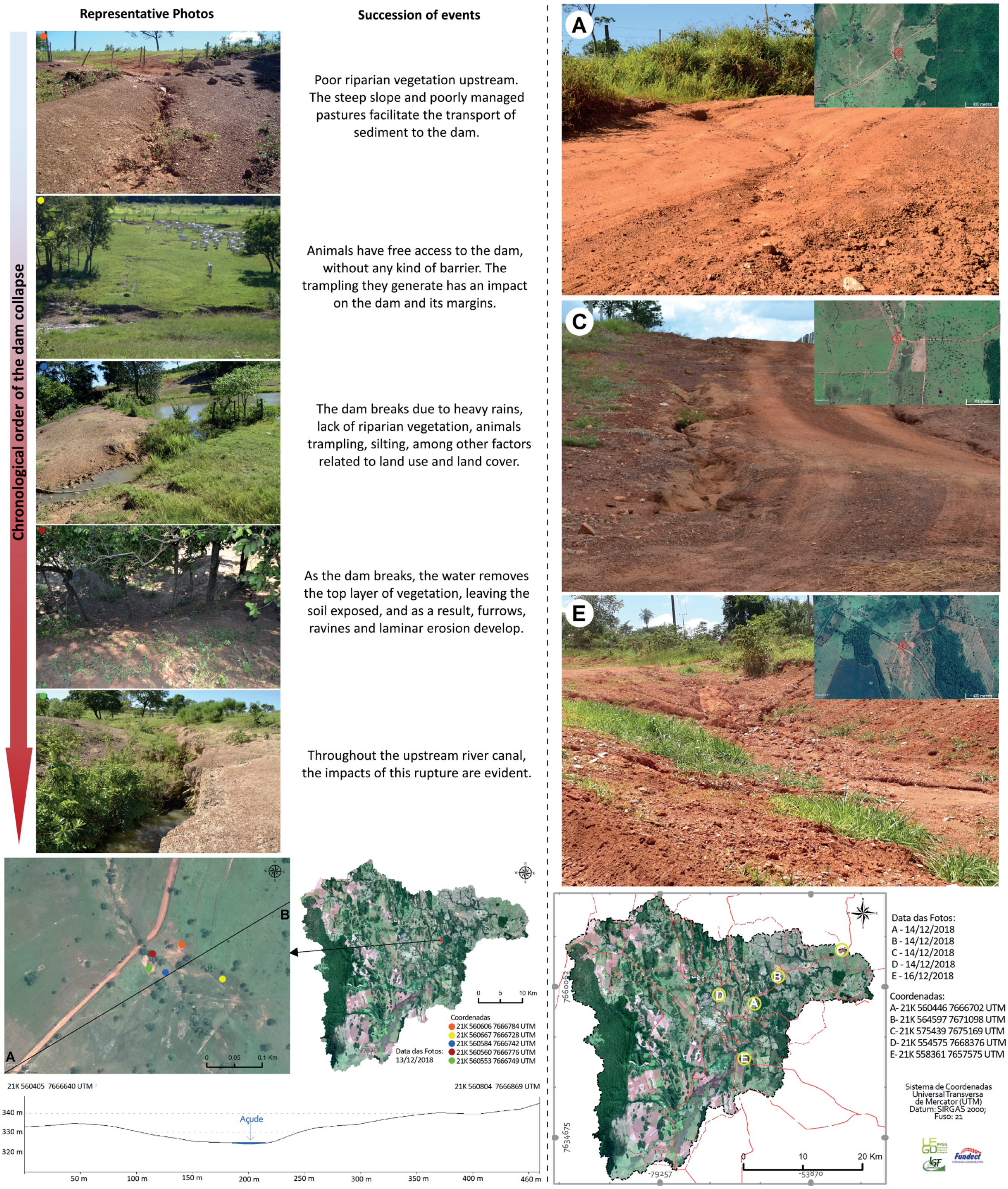


Fig. 8. Examples of the FRW's environmental problems are collapsed dams and erosion on unpaved roads

Thus, the congruent class points to approximately 624.63 km² of the total area, or 47.12%. The high values mask some situations. Actually, 152.12 km² of the total area (around 25% of remnant native vegetation) is encompassed by Serra da Bodoquena National Park. According to Brazil (2000), it allows for the preservation of natural ecosystems of great ecological relevance and scenic beauty, scientific research and development of environmental education and interpretation activities, recreation with nature, and ecological tourism. The legal aspects protect the area, and its steep slopes pose restrictions on anthropic use. Other areas are worth highlighting, such as the State Natural Monuments and Private Natural Heritage Reserves (Monumentos Naturais Estaduais - MNEs and Reserva Particular do Patrimônio Natural – RPPNs), which cover 8.57 km² (about 1.84% of native vegetation remnants). Thus, 452.06 km² of forest remnants remain scattered throughout all regions of the Formoso River Watershed, particularly in steep areas of the upper and mid-course and in the alluvial plains. Yet, residual hills in the Mimoso River sub-basin and the southeastern portion, which present relatively preserved portions, also exist.

It is noteworthy that the Formoso River Watershed, compared to other watersheds in the state of Mato Grosso do Sul, presents significant preserved and conserved areas (Miguel et al. 2013; Braz et al. 2020; Alves, Silva and Brugnolli 2022) due to the fact that a great part of the forest remnants are legally restricted areas and the steep slope does not favor deforestation. Even though deforestation and environmental impacts have occurred in the mid-course of the Mimoso River.

CONCLUSIONS

The Formoso River Watershed's landscape, with its significant changes, contradicts the municipality of Bonito's commitment to conservation and preservation of natural resources. The current scenario shows environmental issues and water resources under threat due to clouding and closures of attractions. The economic model acting in Mato Grosso do Sul and throughout the central region of Brazil has contributed to it.

Defining measurements to maintain the use, recovery, conservation and preservation of native vegetation minimizes negative impacts and ensures respect for the environmental legislation as well as the environmental conditions with their strengths and weaknesses. The present research has generated proposals and suggestions to improve environmental quality and increase environmental resilience. Yet, it proposes mitigation actions to handle the conflicts and incongruities identified, as well as the negative environmental disturbances existing in the Formoso River Watershed. The geotechnologies allowed us to provide a synthesis document that coherently portrays the environmental characteristics of the watershed, and its negative aspects. We conclude that:

- the native remnants (Cerrado and Atlantic Forest) in congruent areas demand maintanance to keep the biodiversity and environmental balance, since the sources of Bonito's main springs are located there;
- there is a need to reforest areas with the greatest incongruity, using species native to the Cerrado and the Atlantic Forest. This will help maintain geoecological balance and promote increased biodiversity.
- surface runoff may be reduced by implementing soil, vegetative and mechanical conservation practices in crops and pastures of the watershed;

We emphasize that genuine appreciation of the Formoso River Watershed may address potential environmental issues in the municipality of Bonito. However, the municipality's scientific, geological, hydrological, tourist, speleological, economic, and social potential continues to grow. ■

REFERENCES

Alves, L.B., Silva, C.A.da; and Brugnolli, R.M. (2022). Diagnóstico ambiental da bacia hidrográfica do córrego Laranja Doce, Mato Grosso do Sul. Revista da ANPEGE, 18(35). DOI: 10.5418/ra2022.v18i35.13822

Angel, S., Sheppard, D., Civco, R., Buckley, A., Chabaeva, L., Gitlin, A., Kraley, J., Parent, and Perlin M. (2005). The Dynamics of Global Urban Expansion. Washington, DC: Department of Transport and Urban Development, World Bank.

Boggiani, P.C., Coimbra, A.M., Gesicki, A.L., Sial, A.N., Ferreira, V.P., Ribeiro, F.B., and Flexor, J.M. (2002). Tufas Calcárias da Serra da Bodoquena, MS - Cachoeiras petrificadas ao longo dos rios. In: Schobbenhaus, C., Campos, D.A., Queiroz, E.T., Winge, M., Berbert-Born, M.L.C. (Edits.) Sítios Geológicos e Paleontológicos do Brasil. 1. ed. Brasilia: DNPM/CPRM - Comissão Brasileira de Sítios Geológicos e Paleobiológicos (SIGEP), v.01. p. 249-259.

Braz, A.M., Mirandola, P.H.G., Pinto, A.L., Chávez, E.S., and Oliveira, I.J.de. (2020). Manejo integrado de cuencas hidrográficas: posibilidades y avances en los análisis de uso y cobertura de la tierra. Cuad. Geogr. Rev. Colomb. Geogr., 29, 69-85. DOI: 10.15446/rcdg.v29n1.76232

Brugnolli, R.M. A cartografia do relevo como subsídio para a análise de um sistema cárstico Leite, E.F., Silva, C.A. Cartografia & geotecnologias: conceitos e aplicações. Porto Alegre: TotalBooks, 2023. DOI: 10.52632/978.65.88393.41.3

Brugnolli, R.M., Berezuk, A.G., and Silva, C.A.da. (2019). A Morfometria da Bacia Hidrográfica do Rio Mimoso, um Sistema Cárstico do Mato Grosso do Sul/Brasil. Revista Confins (Paris), 40:1-22. DOI: https://doi.org/10.4000/confins.19845

Brugnolli, R.M., Chávez, E.S., Silva, C.A.da; and Berezuk, A.G. (2022). Geoecological diagnosis of landscapes of the Formoso River Watershed, Bonito/MS, Brazil. Environmental Earth Sciences, 81, 1-19. DOI: 10.1007/s12665-022-10247-6

Burri, E., Castiglioni, B., and Sauro, U. (1999). Agriculture, landscape and human impact in some karst areas of Italy. International Journal of Speleology, 28, 33-54. DOI: 10.5038/1827-806X.28.1.3

Castro, A.P., and Nielsen, E., (2001). Indigenous people and co-management: implications for conflict management. Environmental, Science and Policy, 4, 229–239. DOI: 10.1016/S1462-9011(01)00022-3

Cohen, B. (2006). Urbanization in Developing Countries: Current Trends, Future Projections, and Key Challenges for Sustainability. Technology in Society, 28, 63–80. DOI: 10.1016/j.techsoc.2005.10.005

CPRM, Companhia de Pesquisa e Recursos Minerais. (2006). Geologia e Recursos Minerais do estado de Mato Grosso do Sul. Brasília, CPRM.

D'Ettorre, U.S.; Liso, I.S.; and Parise, M. (2024). Desertification in karst areas: A review. Earth-Sci. Rev, 253, 104786. DOI: 10.1016/j.earscirev.2024.104786

Dibieso, E. P. (2013). Planejamento ambiental e gestão dos recursos hídricos: estudos aplicados à bacia hidrográfica do manancial do alto curso do rio Santo Anastácio – São Paulo/Brasil. PhD in Geography.

Embrapa, Empresa Brasileira de Pesquisa Agropecuária. (2018). Sistema Brasileiro de Classificação de Solos. 5.ed. Brasília.

Erickson, D.L. (1995). Rural land use and land cover change: implications for local planning in the River Raisin watershed. Land Use Policy, 12, 223-236. DOI: 10.1016/0264-8377(95)00005-X

Fernandes, N.B., Moreau, M.S., Moreau, A.M.S.S., and Costa, L.M. (2010). Capacidade de uso das terras na bacia hidrográfica do Jiquiriça, recôncavo sul da Bahia. Caminhos de Geografia, 11(34): 105-122. DOI: 10.14393/RCG113416076

Ford, D.C., and Williams, P. (2007). Karst Hydrogeology and Geomorphology. John Wiley, Chichester. DOI: 10.1002/9781118684986

Hilson, G. (2002). An overview of land use conflicts in mining communities. Land Use Policy, 19, 65 - 73. DOI: 10.1016/S0264-8377(01)00043-6

Lacerda Filho, J.V., Correia de Brito, R.S., Rodrigues, C.V., Cavalcante, C.O., Silva, M.G., Moreton, C.C., Martins, E.G., Lopes, R.C., Muniz Lima, T., Larizzatti, J.H., and Valente, C.R. (2006). Geologia e recursos minerais do estado de Mato Grosso do Sul. CPRM/SICME, Campo Grande.

Leal, A. C. (1995). Meio ambiente e urbanização na microbacia do Areia Branca-Campinas, SP. Master's in Geosciences and Environment.

Lepsch, I.F., Bellinazi, J.R., Bertolini, D., and Espíndola, C.R. (1991). Manual para levantamento utilitário do meio físico e classificação de terras no sistema de capacidade de uso: 4ª aproximação. Campinas: Sociedade Brasileira de Ciência do Solo.

Mendes, I. A. (1993). A dinâmica erosiva do escoamento pluvial na bacia do Córrego Lafon – Araçatuba – SP. PhD in Geography.

Miguel, A.E., Brugnolli, R.M., Oliveira, W. de; and Brugnolli, C.A.C. (2013). Uso e ocupação do solo e análise morfométrica da bacia hidrográfica do córrego Bom Jardim, Brasilândia/MS. Revista Geonorte, 4(11):72–84.

Narendra, B.H.; Siregar, C.A.; Dharmawan, I.W.S.; Sukmana, A.; Pratiwi; Pramono, I.B.; Basuki, T.M.; Nugroho, H.Y.S.H.; Supangat, A.B.; and Purwanto; et al. (2021). A Review on Sustainability of Watershed Management in Indonesia. Sustainability, 13, 11125. DOI: 10.3390/su131911125

Ochieng Odhiambo, M., (2000). Oxfam Karamoja Conflict Study: a Report. Oxfam, Kampala.

Parise, M. (2012). Management of water resources in karst environments, and negative effects of land use changes in the Murge area (Apulia, Italy). Karst Development: Original Papers, 2(1): 16-20.

Parise, M; de Waele, J., and Gutierrez, F. (2009). Current perspectives on the environmental impacts and hazards in karst. Environmental Geology, 58, 235–237. DOI: 10.1007/s00254-008-1608-2

Ramalho Filho, A., and Beek, K. J. (1995). Sistema de avaliação da aptidão agrícola das terras. 3. ed. Rio de Janeiro: EMBRAPA-CNPS.

Ribeiro, A.F.N. (2018). Que Bonito é esse? Disputas territoriais em terras do agro-eco-turismo. Revista Entre-Lugar, 9(18): 37–67. DOI: 10.30612/el.v9i18.8824

Sallun Filho, W., Karmann, I., and Boggiani, P.C. (2004). Paisagens Cársticas da Serra da Bodoquena (MS). In: Litologia do continente Sul-americano: evolução da obra de Fernando Flávio Marques de Almeida, Chapter: XXV, Publisher: Ed. Beca, Editors: Virgínio Mantesso-Neto, Andrea Bartorelli, Celso Dal Ré Carneiro, Benjamin Bley de Brito-Neves, 424-433.

Silva, F. F. da., and Morais, F. de. (2016). Índice de perturbações ambientais em áreas cársticas do estado do Tocantins – primeira aplicação no Brasil. Revista Brasileira de Geografia Física, 09(3), 766–777. DOI: 10.26848/rbgf.v9.3.p766-777

Silva, M.A., Freitas, D.A.F., Silva, M.L.N., Oliveira, A.H., Lima, G.C., and Curi, N. (2013). Sistema de informações geográficas no planejamento de uso do solo. Revista Brasileira de Ciências Agrárias, 8(2), 316-323. DOI: 10.5039/agraria.v8i2a2289

Silveira, G.R.P., Campos, S., Garcia, Y.M., Silva, H.A.S., Campos, M., Nardini, R.C., and Felipe, A.C. (2013). Geoprocessamento aplicado na determinação das subclasses de capacidade de uso do solo para o planejamento conservacionista. Comunicata Scienia, 4(4), 330-336. DOI: 10.14295/cs.v4i4.223

Spring. (1996). Integrating remote sensing and GIS by object-oriented data modelling. Camara G, Souza RCM, Freitas UM, Garrido J Computers & Graphics, 20(3), 395-403.

Tavares, A.S., Vieira, M.S., and Uagoda, R.E.S. (2023). Desafios e Alternativas na Simulação da Dinâmica Hidrológica e Sedimentológica em Sistemas Cársticos. Revista Brasileira de Geografia Física, 16(4), 1714–1731. DOI: 10.26848/rbgf.v16.4.p1714-1731

Usgs, United States Geological Survey. (2023). Earth Explorer. Available in: https://earthexplorer.usgs.gov/. Accessed in: May. 2023.

Van Beynen, P.E., Brinkmann, R., and Van Beynen, K.M. (2012). A sustainability index for karst environments. Journal of Cave and Karst Studies, 74(2), 221–234. DOI: 10.4311/2011SS0217

Veni, G., Duchene, H., Crawford, N.C., Groves, C.G., Huppert, G.N., Kastning, E.H., Olson, R., and Wheeler, B.J. (2001). Living with karst, a fragile foundation. AGI Environmental Awareness Series. American Geological Institute, 4.

Wilson, C. (2014). Spectral analysis of civil conflict-induced forced migration on land-use/land-cover change: the case of a primate and lower-ranked cities in Sierra Leone. International Journal of Remote Sensing, 35(3), 1094–1125. DOI: 10.1080/01431161.2013.875633

Wu, Q., and Wang, L. (2024). Farmland hydrological cycle under agroforestry systems and efficient use of water resources in the karst desertification environment. Heliyon, 10, e35506. DOI: 10.1016/j.heliyon.2024.e35506

Zavattini, J. A. (1992). Dinâmica climática no Mato Grosso do Sul. Geografia, 17(2), 65-91.