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Research paper

Environmental conflicts in municipality areas: land use policy for zoning regulation

Conflitos ambientais em áreas do município: política de uso do solo para regularização de zoneamento municipal

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ABSTRACT: The growing expansion of socioeconomic activities without considering the potentialities and limitations regarding the land use constitutes a potential source of deterioration of the environment. The present work aimed to diagnose the areas of land use conflict in the municipality of Batatais-SP. The methodological procedure consisted of geographic information systems and remote sensing techniques. The municipal area was regionalized into hydrological response units (HRU). The quantitative data of area, length of the drainage network and roughness number were determined, and the processes and their interrelationships were analyzed. The distribution of aptitude classes for land use was confronted with the current land use and allowed the identification and quantification of the land use conflict. Zoning indicated that, from 452.46 km^2 of the municipality's area, 28.67% are assigned to conflict class 1 and present risks or severe permanent limitations when used for annual crops and pastures. At higher spatial levels, land use conflict influences sustainable development. States grant authority to pass ordinances and regulations, and municipal governments have autonomy to control land use within their jurisdictions, if it do not conflict with other laws. The land use conflict technique establishes an orderly pattern and can serve as a tool for municipal zoning in regulating land use.

Keywords: Environmental analysis. Ruggdeness number. Geographic Information System (GIS). Land use policy.

RESUMO: *A crescente expansão das atividades socioeconomicas sem considerar as potencialidades e limitações quanto ao uso das terras constitui fonte potencial de deterioração do meio ambiente. O presente trabalho teve como objetivo diagnosticar as áreas de conflito de uso do solo no municipio de Batatais-SP. O procedimento metodológico constou de técnicas de sistemas de informações geográficas e de sensoriamento remoto. A area municipal foi regionalizada em unidades de resposta hidrologica (URH). Os dados quantitativos de area, comprimento da rede de drenagem e coeficiente de rugosidade foram determinados e os processos e suas inter-relações foram analisdos. A distribuição das classes de aptidão de uso foi confrontada com o uso atual do solo e possibilitou a identificação e quantificação do conflito de uso. O zoneamento indicou que, de 452,46 km^2 da área do município 28,67% são atribuídos à classe 1 de conflito e apresentam riscos ou limitações permanentes severas quando usadas para culturas anuais e pastagens. Em níveis espaciais mais elevados, o conflito de uso do solo influencia o desenvolvimento sustentavel. Os estados concedem autoridade para aprovar decretos e regulamentos, e os governos municipais apresentam autonomia para controlar o uso da terra dentro de suas jurisdições, desde que não entrem em conflito com outras leis. A tecnica de conflito estabelece um padrão ordenado e pode servir como ferramenta para o zoneamento municipal na regulamentação do uso do solo.*

Palavras-chave*: Análises Ambientais. Coeficiente de Rugosidade. Sistema de Informação Geográfica (SIG). Política De Uso Do Solo.*

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INTRODUCTION

To understand the process of the land use land changes is necessary to consider the interests of administrative, economic, social, and environmental management. Public policy primarily must use spatial and land use plans to develop code regulations and instruments for land use policies. Thus, from the anthropic activities, it is essential to identify potential strategies and plans to develop targets that are specific, measurable, and actionable. Further, developing indicators to monitor land use land changes would enhance accountability for local relevant land-use nexus (MORAIS et al., 2023; VALERA et al., 2017).

The natural vegetation covers changes in the landscape and conflicts occur, especially when land use differs from land use potential for economic uses or in conservation areas, according to Brazilian environmental legislation (VALERA et al., 2019). They also occur when land use is associated with land use changes above the land capability, wich groups soils are based on their potential for agricultural and other uses.

The term "land use conflict" refers to a situation where there is a discrepancy on the land use of a certain zoning by a wrong management or undertakings of a better land use for the space and its proper management. A way to evaluate the space is to verify the physical morphometric characteristics of catchment areas as indicators of land use suitability, as McDowell et al. (2018) describes an application of the concept to inform sustainable productivity within environmental constraints. According to the Ruggedness Number (RN) methodology, which allows identifying areas of natural erosion by basin relief and the net length of drainage network and slope steepness with its length and has implications on the structural complexity and erosion potential of the landforms (PISSARRA, 2002). The conflict by mapping potential land use and current occupation (PISSARRA, 2002; VALLE JUNIOR et al., 2013; VALLE JUNIOR et al., 2014) shows the land use suitability using the Ruggedness Number. Introduced by Strahler (1952), the Ruggedness Number was originally used as an indicator of hydrological dynamism (SCHUMM, 1956; MELTON, 1957).

The land use conflict directs the activity of agriculture, livestock, or forestation or even of forest preservation according to the potential use of the land. Thus, land use conflicts can occur in two situations: first is when the management of land use contradicts the recommendation made from the Ruggedness Number. The second is when land potential is underestimated, with land use causing low productivity with inappropriate or condemned techniques (BARACUHY et al., 2003).

In the development of relationships between the slope and drainage network variables by area of a watershed, the Ruggedness Number (RN) is a value adopted as a land capability and can be obtained following the approach of Rocha and Kurtz (2001), Pissarra (2002) and Valle Junior (2008). The Ruggedness Number can be divided into 4 classes of land use suitability. Class 1: characterizes areas with a low RN, which are suitable for agricultural cultivation, as they correspond to poorly dissected areas and flat to undulating slope. Class 4: with higher RN value, characterizes areas intended for forest occupation, and the soils of these areas are sloping and/or highly dissected. The classes with intermediate values of RN 2 and 3 characterize, respectively, suitable areas for cattle grazing and pasture/forestry (ROCHA; KURTZ, 2001; PISSARRA, 2002; VALLE JÚNIOR, 2008).

The dynamics of erosive processes and their relationship with land use evolution and lithopedological characteristics were studied by Pinton and Cunha (2008), showing the intrinsic link in the development of the erosive process in land occupation, being extremely

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relevant for environmental planning. For Silva Neto (2012), the classification of land use capability seeks to establish guidelines for more efficient land uses. In this sense, land is divided into three main categories: land suitable for many uses, including intensive cultivation; land unsuitable for intensive cultivation but suitable for pasture and reforestation or maintenance of natural vegetation; and land unsuitable for cultivation, recommended for protection of flora, fauna or recreation.

Throughout its history, man has been exploring the earth with little planning and conservation. In this sense, the representation of plant communities in geographic space can be analyzed using techniques of geographic information systems - GIS. According to Pereira et al. (2012), the systematization of reality in models that can encompass as many variables as possible is supported by methodologies that refer to the computational environment. According to Pissarra et al. (2013), the study of land use land change using GIS techniques allows to understand the distribution of vegetation cover in watersheds and landscapes, and the interpretation of the process responsible for this distribution effectively contributes to the study of the environmental conditions.

The land use conflict in the municipality of Batatais-SP, Brazil, is characterized by changes in permanent preservation areas and lack of legal reserve implementation in the properties, advocated in Brazilian environmental legislation. This municipality is in the process of urbanization, and the areas surrounding the urban perimeter, which have not yet been urbanized, should receive special attention regarding expansion planning (ZANATA; PISSARRA, 2012). The present study aimed to diagnose the areas of land use conflict in the municipality of Batatais-SP., Brazil, if the methodology and techniques of GIS used will indicate efficiently and effectively the areas with land use conflict in municipality areas to define land use policy for zoning regulation.

METHODS

Study area

The study was conducted in Batatais, São Paulo State, Brazil (**Figure 1**), located at a latitude of 20º53'28 "south and longitude of 47º35'06" west.

The municipality of Batatais has an area of approximately 851 km², represents 0.3427% of the state of São Paulo, from its 7,5068 km², and average population of 56,476 inhabitants (IBGE, 2012). The climate is classified as Cwa in the Köppen-Geiger classification, Tropical (mild) with dry winter, with the main rain months being from November to March. The average annual temperature is 21°C. It has predominant vegetation of the Cerrado and Semideciduous Forest biomes, in transition environments.

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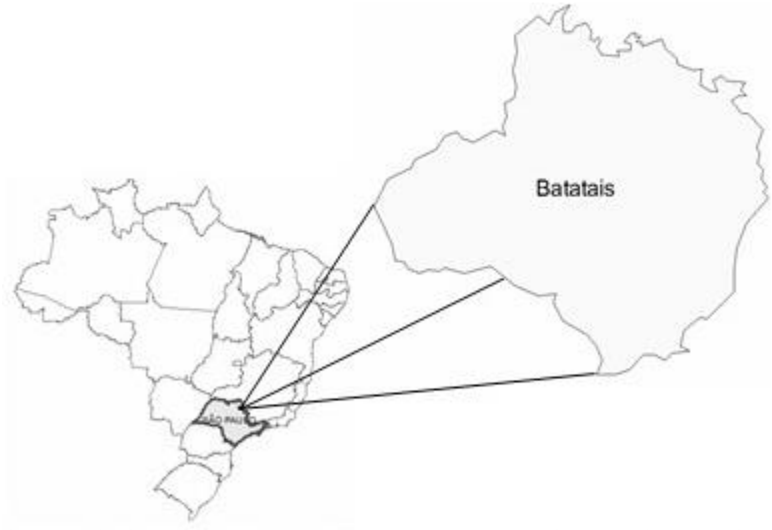
Figure 1. Location of Batatais municipality, São Paulo, Brazil



Database and computer programs

Two scenes of Shuttle Radar Topography Mission (SRTM) radar images, 30 m spatial resolution, WGS84-Zone 23 K (SF-23-VA and SF-23-VC) and a Landsat 8 optical sensor image mosaic with 30 m spatial resolution and 16-day temporal resolution, Datum WGS84, were used to compose the mapping base and for data collection. The images are available for free on the websites of the Empresa Brasileira de Pesquisas Agropecuárias (EMBRAPA) and the Instituto Nacional de Pesquisas Espaciais (INPE).

Digital modeling was performed using ESRI GIS and Mapping Software ArcGIS software, licensed to the FCAV/UNESP at the Geomatic Laboratory. A routine was performed in the ArcGIS Catalog module to create a platform for storing and organizing the data and products (thematic maps). The area of the municipality was subdivided into hydrological response units (HRU), done by the topographic and morphometric characteristics using the modeling extension of the SWAT (Soil and Water Assessment Tool), model program developed by the Blackland Research Center of the Texas Agricultural Station and the USDA Agricultural Research Service, A&M University.

Thematic Maps

The potential land use map was elaborated based on the Ruggdeness Number (RN), and the greater the potential for the erosive process of the soil to occur, when the greater the value of the RN. This parameter directs the potential land use in terms of its classes of agriculture, livestock and reforestation or permanent preservation activities. **Table 1** shows the classifications and indicative of potential land use and respective RN weights.

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Table 1. Classes of potential land use, indication of land use and weight of Ruggdeness Number (RN).

Classes	Potential land use	RN weight
A	Agriculture	1
B	Livestock	2
C	Livestock/Forest	3
D	Forest	4

The Ruggdeness Number (RN) was calculated by the equation RN = D**x**H (ROCHA; KURTZ, 2001); where RN is the Ruggdeness Number, D is the drainage network density ($km.km^{-2}$) and H is the mean slope (%) of each HRU. The municipality area was divided into 17 HRUs, on which morphometric characteristics were analyzes, such as area (km^2), total drainage network lengths (km), drainage density ($km.km^{-2}$) and mean slope (%), as aided by the ArcGIS ARCSWAT extension.

After determining the RN of each HRU, its amplitude (A) and interval (I) were calculated, as follows: A = (highest RN value - lowest RN value) and I = A / 4, in which, denominator 4 represents the number of land uses classes (A, B, C, D).

To define the domain ranges for each potential land use, it was started with class A, to include the lowest value of RN. After that, the domain range value for each potential class was added, thus defining the upper range limit. The remaining domains were defined according to the same procedure, observing that the lower limit value of the subsequent domain was set from the upper limit of the preceding class.

The current land use map was generated from the Landsat 8 orbital sensor image mosaic (red, green, blue and near infrared spectral bands - RGB 5,4,3) by the supervised classification method. For comparison purposes, the standardized minimum distance and maximum likelihood methods were used in the supervised classification aiming to find the one that better represents the area. Each pixel in the image was labeled according to land use, and using statistical algorithms to recognize spectral patterns, three land use classes were considered, with each weight assigned (**Table 2**).

Table 2. Classes of current land use and weights

Classes	Current land use	Current land use weight
Class A	Agriculture	1
Class B	Pasture	2
Class C	Forest	3

In the standard minimum distance method, a point in the multidimensional space defined by the statistical mean of each considered spectral band is taken as reference for each class. The algorithm associates each unknown pixel with the nearest average class (IBGE, 2001). Spectral symmetry characterizes this method, in which each pixel inside and outside the training areas will be evaluated and associated with the class to which it is most similar (MOREIRA, 2007). The likelihood method has a training area by selecting from the image, with pixel model that is representative for each land use target. After selecting the pre-established land use classes, the GIS, by means of specific equiprobability calculations, adapts the remaining unknown or unclassified pixels to the classes (IBGE, 2001; JENSEN, 2009).

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The map of land use conflict areas was obtained from the cross-classification method, which consists of the superposition of two information planes (map algebra), from the overlapping of the potential land use map with the current land use and map, enabling the elaboration of the use conflict map. The procedure was processed with the aid of ESRI ArcGIS Desktop software, allowing the delimitation and classification of areas of land use conflict, according to the methodology proposed by Valle Junior et al. (2013) and Valle Junior (2008). As an example, if the weight of RN (**Table 1**) is indicative of land use for forests, and currently their area is used for agriculture (**Table 2**). After cross-classification (4 – 1 = 3), a category 3 conflict can be defined and so on (**Table 3**). When the result of the cross classification is negative or zero, it indicates area of agricultural expansion or area without land use conflict.

Table 3. Description of land use conflict categories (environmental degradation)

Class weight	Land Use Weight	Conflict Categories	Description
4 – 3 3 – 2 2 – 1	= 1 = 1 = 1	Category 1	Land with severe permanent risk or limitation when used for annual crops and pastures; Its use should be guided by the implementation of joint soil conservation techniques (vegetative, mechanical).
4 – 2 3 – 1	= 2 = 2	Category 2	Land unsuitable for intensive cultivation, but still adapted for native pasture, reforestation, or environmental preservation.
4 – 1	= 3	Category 3	Land unsuitable for intensive cultivation and pasture, but still adapted for reforestation or environmental preservation

Adapted from Valle Junior et al. (2013), Valle Junior (2008), Pissarra (2002).

RESULTS AND DISCUSSION

Potential land use for each HRU was determined within the range (I) of the Ruggdeness Number (RN) (**Table 4**). The variation ranged from 2.87 to 11.91. The domain of RN calculated in the range of variation determines the values of amplitude (A) of 9.04 and the calculated range (I) of 2.26.

Table 4. Potential land use classes, Ruggdeness Number (RN) domain ranges and Indicative of potential land use for Batatais Municipality, SP

Potential Land Use Classes	RN	Indicative of potential land use
A	2.87 – 5.12	Agriculture
B	5.12 – 7.38	Livestock
C	7.38 – 9.64	Livestock/Forestry
D	9.64 – 11.91	Natural Forest

Class "A", with indicative for agriculture, is represented by the lowest values of RN, in contrast, class "D", with indicative for natural forest is represented by the highest values of RN.

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This is since the higher the value of the RN between HRUs, the greater the suitability for natural erosion processes, which justifies the purpose of areas with greater RN for permanent preservation areas since its use by anthropic activities would cause the deterioration of those environments. Once the ranges for each suitability were determined, the HRUs were classified within the suitability corresponding to their respective RN values and weights (**Table 5**).

Table 5. Attributes of the hydrological compartments of Batatais, SP

HC*	Area**	%***	Declivity ****	Drainage Density *****	Ruggdeness Number (RN)	RN Classification	RN weight
01	63.21	7.43	7.98	0.66	5.24	Class B	2
02	9.61	1.13	10.32	0.58	6.03	Class B	2
03	6.71	7.37	9.15	0.55	5.05	Class A	1
04	108.21	12.72	9.95	0.77	7.67	Class C	3
05	75.67	8.89	9.03	0.60	5.40	Class B	2
06	14.08	1.65	9.46	0.37	3.46	Class A	1
07	15.69	1.84	6.34	0.45	2.87	Class A	1
08	67.51	7.93	8.18	0.77	6.32	Class B	2
09	49.45	5.81	10.19	0.73	7.43	Class C	3
10	55.21	6.49	6.87	0.76	5.25	Class B	2
11	60.21	7.08	8.32	0.60	5.00	Class A	1
12	42.05	4.94	11.34	0.96	10.91	Class D	4
13	20.80	2.44	7.41	0.64	4.74	Class A	1
14	60.30	7.09	8.06	0.63	5.10	Class A	1
15	61.50	7.23	9.12	0.69	6.25	Class B	2
16	19.51	2.29	10.80	0.84	9.03	Class D	4
17	65.29	7.67	15.93	0.75	11.91	Class D	4

*HC - Hydrological Compartment; **Area: km^2; %*** - Percentage in relation to the total area of the municipality; **** Declivity - %; ***** Drainage Density - km/km^2.

The HRU with the largest territorial extension was classified as class C, indicating the transition between livestock and forest. However, twelve of the seventeen HRus of the municipality have six classes for agriculture (A) and six classes for livestock (B). Based on the Ruggdeness Number (RN), the potential land use map was obtained for the municipality of Batatais-SP (**Figure 2**).

The surfaces were established by the RN coefficient, indicative for agriculture, livestock, livestock/forestry and natural forest. The RN is an environmental parameter that directs the potential land use, evidencing the susceptibility of soil to erosion. In **Figure 2**, the area's most susceptible to erosion are observed (Classes C and D).

Sampaio et al. (2010) stated that land use capacity and RN are equivalent in 99.9% of cases. As a result, they proposed replacing land use capacity using RN, as it is a faster method and without the need for field sampling, mainly facilitating the economic aspect.

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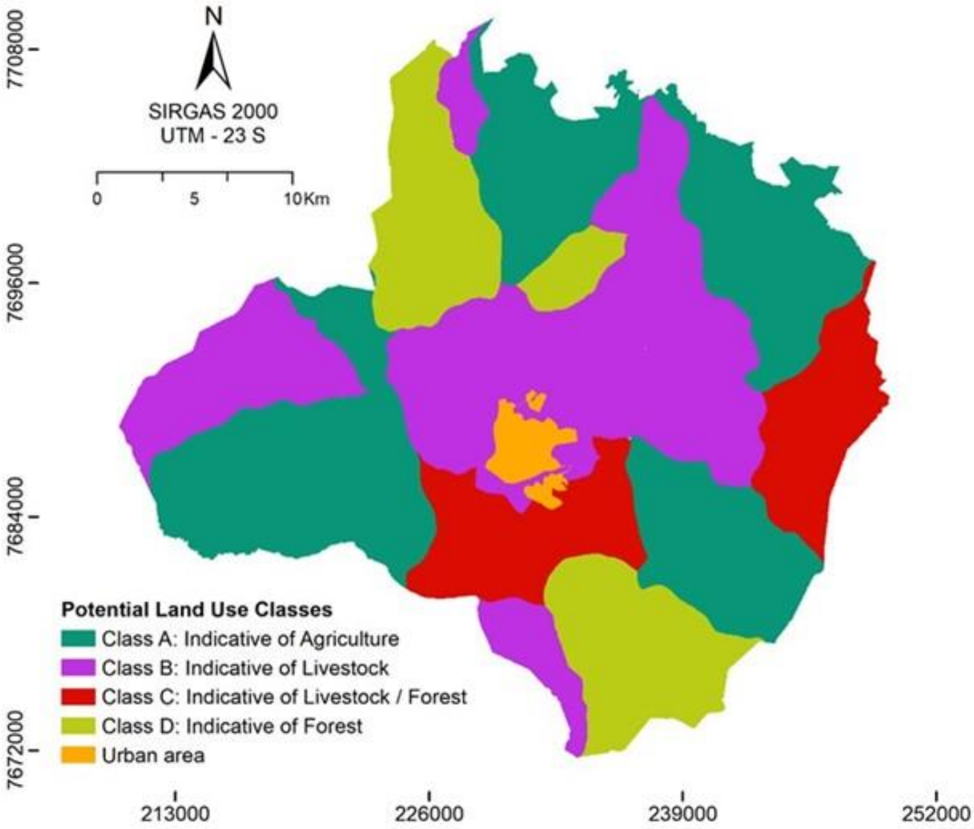
Figure 2. Map of potential land use as a function of RN for the municipality of Batatais-SP



The lands were suitable for agriculture, livestock, livestock/forestry and natural forest, respectively, 316.45; 279.75; 111.63 and 143.17 km^2, equivalent to 37.19%; 32.87%; 13.12% and 16.82% of the municipality area (**Table 6**).

Table 6. Classes and potential land use, and their respective areas of occurrence in Batatais, SP.

Classes and potential land use	Areas	
	(km^2)	%*
A – Agriculture	316.45	37.19
B – Livestock	279.75	32.87
C – Livestock/Forest	111.63	13.12
D – Forest	143.17	16.82
Total	851	100

* Percentage in relation to the total area of the municipality.

The land use as the anthropic actions and the native natural environments of the region can be seen on **Table 6**. In these native areas, the actions for the preservation of the natural heritage are indicated, as recommended by the Brazilian environmental legislation. The map in **Figure 3** shows the spatial distribution of land use of Batatais-SP, considering the classes of pasture, agriculture, forest and urban area.

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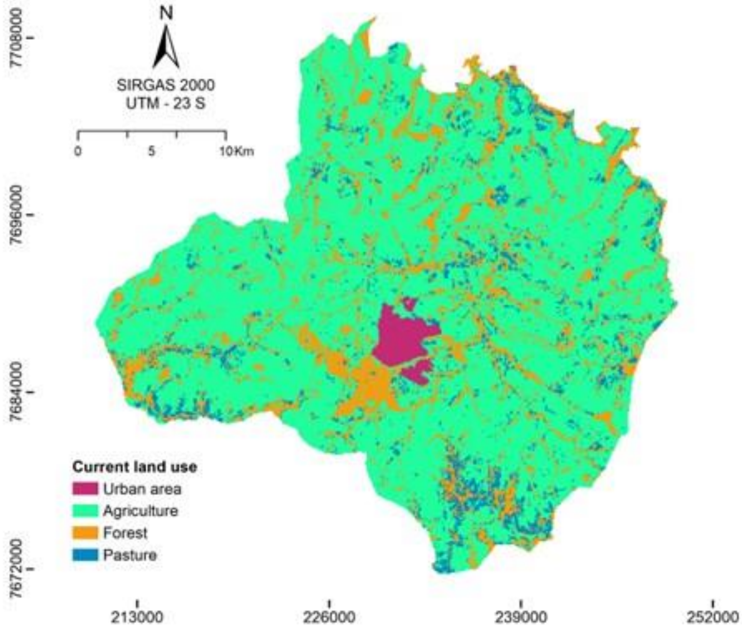
Figure 3. Map of land use and occupation of the municipality of Batatais-SP



The current land use identified in Batatais-SP showed areas of 632.15 km^2 of agriculture, 137.14 km^2 of forest, 65.35 km^2 of pasture and 16.36 km^2 of urban area, respectively, 74.28%, 16.12%, 7.68% and 1.92% of the area of the municipality of Batatais (**Table 7**).

Table 7. Current land use and their respective areas in Batatais, SP

Current land use	Areas	
	(km^2)	%*
Agriculture	632.15	74.28
Forest	137.14	16.12
Pasture	65.35	7.68
Urban area	16.36	1.92
Total	851	100

* Percentage in relation to the total area of the municipality.

The most expressive land use class is represented by agriculture, with larger area for sugarcane cultivation. This crop originates the main raw material for sugar and ethanol production, being part of the economic base of the region. Cultivation is usually done extensively, and plantations occupy many contiguous areas. As cultivation and cutting are performed by machines and tractors, soil management occurs intensely. At the same time as production, management should be conservationist. In the use of agriculture are also found the diverse crops of coffee, reforestation with pine and eucalyptus, citrus, among other annual crops.

Another prominent land use is pasture. This system has long periods of land occupation with animals. Despite producers' concern to improve the use of forage products, proper management does not occur. One of the main problems of this system is the lack of

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conservation management, which usually culminates in soil degradation. A pasture is considered degraded when a large area is overgrown with weeds or uncovered soil surfaces. This degradation causes a detachment of the soil, culminating in erosive furrows. According to Pinton and Cunha (2008) and Valera et al (2017), the development of the linear erosive process is directly related to the natural characteristics of the environment.

For Silva Neto (2012), the intensification of erosion processes is often associated with inadequate land use, which usually occurs without prior knowledge of the area used. In this process of appropriation of nature, any area can be explored, thus disrespecting the physical-natural limits of landscapes.

Table 8 shows the values in km^2 and respective percentages of the three conflict categories identified. Of the municipality's 851 km^2, 452.46 km^2 are in conflict zones. Areas that present severe permanent risks or limitations when used for annual crops and pastures should be guided by the implementation of joint soil conservation techniques. The highest percentage of occurrence is in conflict category 1, which occupies 241.95 km^2 corresponding to 28.43% of the municipality's area.

Table 8. Conflict categories of land use and their respective areas of occurrence in Batatais, SP

Conflict Categories	Areas	
	(km^2)	%*
Category 1	241.95	28.43
Category 2	105.74	12.43
Category 3	104.77	12.31
Total	452.46	53.17

* Percentage in relation to the total area of the municipality.

The spatial distribution of the areas of the land use conflict categories on Batatais-SP is shown in **Figure 4.** A conflict may exist, but not necessarily generate an anthropogenic erosive process. However, the importance of proper implementation of management practices in agricultural activities in the region must be emphasized.

Rodrigues, Pissarra and Campos (2011) stated that the impact on the environment is seen in erosive aspects, in places with the main activity of intensive agriculture, in sugarcane vegetation cover and Citrus crop. Conflict category 2, which represents land unsuitable for intensive cultivation but still adapted for native pasture, reforestation, or environmental preservation, comprises 105.74 km^2, corresponding to 12.43% of the municipality's area. In these areas, conservation practices are recommended bearing in mind the importance of reducing soil loss and, consequently, increasing nutrient supply to plants. The great potential of forest systems is a strategy for soil conservation (CANDIDO et al., 2010).

On **Table 8**, about 104.77 km^2 is in the conflict category 3, corresponding to the land unsuitable for intensive crops and pastures, but still adapted for reforestation or environmental preservation, representing 12.31% of the municipality's area. According to Campos et al. (2009), permanent preservation areas play a vital role in a ecosystem, as those areas are responsible for maintaining, preserving, and conserving the natural resources. Thus, those areas must be covered with the natural forest, since the vegetation cover minimizes the erosive effects and contribute to the regularization of the water flow, reducing the silting of the water courses and reservoirs and bringing direct benefits to the

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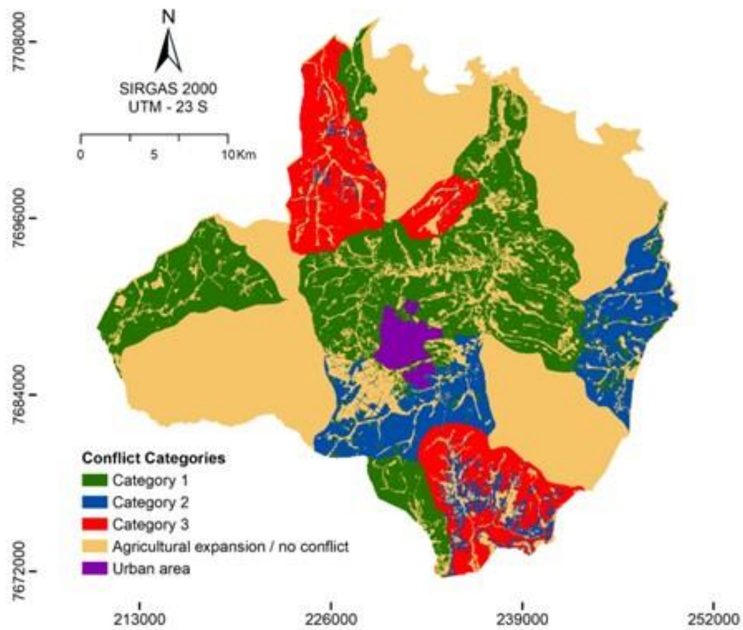
fauna and humans. According to Morais et al. (2023); Valera et al. (2017), modifications in land use are one of the most impactful ways of accelerating soil erosion. The land use land changes have an effect as the loss of fertile topsoil cover sends millions of tons of sediments into lakes and reservoirs. This erosion process changes the ecosystems and impacting agricultural production and water quality (PACHECO; FERNANDES, 2016).

Figure 4. Map of land use conflict in the municipality of Batatais-SP



The environmental conflicts in municipality areas were a very useful methodology for land use policy for zoning regulation. The analysis permit to understand the origin of the conflicts due to inadequate management by anthropic actions. In many cases, by irregular land uses without considering the Brazilian environmental legislation. Over the decades of social and economic development in the region, inadequate management took place without previous studies that determined rules for their occupation, causing impacts on the environment, which could be mitigated by defining zoning regulation by land use conflict methodology, which are of great value for the elaboration of a master plan for the development of the municipal geographic space (CARVALHO; GALLO JUNIOR, 2012).

It is important to note that federal, state, and municipal laws safeguard existing natural resources in the area and that the region should adopt plans for land uses zoning, supported by land uses policies, as well as rigorous inspection to preserve these resources for generations future. This work highlights the need to verify the limitations regarding land uses, which can alter the dynamic balance of the natural characteristics of the landscape and compromise the environmental system and the quality of human life. Thus, it is necessary to better understand the dynamics of this area to establish guidelines that support the land use, better management, conservation measures of natural resources and the adoption of safer restrictions on land use.

Improving policy co-ordination mechanisms to the Sustainable Development Goals can help improve a better land use management. Policy instruments relevant to the land-use nexus support and intensify land reform efforts to ensure food and hydric security. This

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aids the land use design using geoprocessing and remote sensing techniques can be the instruments required to manage land-use systems for environmental impact assessments and spatial planning by providing incentives to rural producers to invest in more sustainable practices Land-use policies can otherwise cease to function effectively and previous environmental gains can be reversed, mainly for payment for ecosystem services.

CONCLUSIONS

The analysis of the conflict categories shows that the conflict category 1, referring to lands that present significant risks or limitations when used for annual crops and pasture, represents the majority with 241.95 km^2 of the municipality of Batatais, which corresponds to 28.43% of the municipality's area. Conflict category 2, which represents land unsuitable for intensive cultivation, but still adapted for native pasture, reforestation, or environmental preservation, comprises 105.74 km^2, which corresponds to 12.43% of the municipality's area.

Conflict category 3, corresponding to land unsuitable for intensive cultivation and pasture, but still adapted for reforestation or environmental preservation, represents 12.31% of the municipality's area. This aids the land use design using geoprocessing and remote sensing techniques can be the instruments required to manage land-use systems for environmental impact assessments and spatial planning by providing incentives to rural producers to invest in more sustainable practices.

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