

The Use of Remote Sensing and Landscape Metrics to Analyze Land Use Evolution in Rural Areas of the Municipality of Passo Fundo/RS (Brazil)

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Abstract: The use of remote sensing in the design of land use mapping allows analyses of landscape evolution during a certain period of time which helps studies in a global scope. The objective of this study is to identify and analyze changes in characteristics of rural land use in the municipality of Passo Fundo, located in the state of Rio Grande do Sul, Brazil, during the years 2001 and 2020, through images taken from the Landsat TM-7 and TM-8 satellites. Methodologically, satellite images were classified by supervised methods, generating thematic maps, and taking into account the following groups: tillage (growing area), forest, exposed soil and water resources. Results demonstrated that the process of connecting agricultural crop patches went from 5.495 in 2001 to a figure of 10.812 in 2020, thus having an increase of 96%.

Key words: Design, urban and rural, landscape, remote sensing, land use.

1. Introduction

The effects of land use and land cover changes have reached a new dimension in the scientific world with remote sensing studies that help understand temporal variations over the years [1]. The possible changes that have occurred with the evolution of environmental impacts and climate change in the last decades have triggered new discussions at local and global levels [1, 2].

At the global level, it addresses issues of interest related to land use/cover versus global warming to understand biodiversity and climate change [3]. Thus, the issues of social and economic interest of the world population are related to the availability of food and water [2].

Regional development becomes a multidimensional approach focused on the future, with actors actively involved in a decision-making process, coordinating efforts to integrate different types of solutions to regional problems in the environmental and social spheres [4]. In this sense [5], it is important to mention and discuss the changes that have occurred in land use over time, by taking into account sustainable factors.

At the local level, reflections on changes of land use and land cover are more detailed and specific, such as direct soil contamination and erosion [5]. Within social and economic aspects, such changes affect job offers, quality of life and environmental aspects caused by the expansion of urban areas and/or deforestation of areas for agricultural cultivation [2, 5]. Depending on the region, land use change has negative and irreversible consequences, both for people and for the environment. However, some changes have

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contributed to the increase in food production, as well as to a more efficient use of space [2].

Thus, in addition to helping with food security, it often provides crop diversification or expansion of the local production [5]. In terms of contextualization, it is necessary to analyze possibilities for sustainable actions and to verify the logic of the territorial organization in addition to economic analysis. However, each region has its own similarities and inequalities [6], and the global problem related to the increase in population and the amount of land should be taken into account as there will be a need to double food production. Therefore, it is necessary to meet food demands and the land use in a sustainable way to achieve resilient intensification [7].

Land use and land cover changes have sparked numerous initiatives to understand their processes [2]. Also, it is possible to determine different regions through impact assessments to a greater or lesser degree.

A more sustainable, responsible and conscious society is expected as a result of the contributions to issues regarding the vision of land cover definition and use. In recent years there has been an increase in use of natural resources, as well as a strong expansion of environmental degradation. However, in some regions, concerns about overconsumption of natural resources have increased [8].

Land use concept comprises the activities of using space such as agricultural, livestock and housing tasks, and therefore land use can directly interfere with land cover [5]. Thus, there is a need for recognition and spatialization of land use/cover, and therefore satellite images are used to generate graphical representation maps, resulting from the mappings designed with the use of Geographic Information Systems (GISs) [9].

The validation of different scenarios is related to comparisons to previous mappings [9]. In addition, mapping can provide with different groups of land use and occupation, such as: urbanized areas, exposed soil, water resources, native forest and tillage (growing

area) [5, 9].

At this point there is an important aspect which is the opportunity to discuss the degree of urgency, as well as actions to mitigate land misuse and to increase the interdisciplinarity of research in sustainability [10]. It is necessary to expand solutions to societal needs while developing new studies at the local level in order to understand and manage the impacts of some decisions [10], in this case [5], based on geospatial information.

The general objective of this study is to analyze changes in the characteristics of rural land use in the municipality of Passo Fundo (RS), during 2001 and 2020, through images taken from the Landsat TM-7 and TM-8 satellites.

2. Methods and Materials

The municipality of Passo Fundo is located at the Planalto Médio region, 28°15'46" latitude and 52°24'24" longitude, in the north of the State of Rio Grande do Sul, Brazil. It is considered the largest city in the northern part of the state and is approximately 287 km from Porto Alegre. Passo Fundo occupies an area of 780,317 km² and has approximately 201,767 inhabitants [11].

The territorial division of the municipality of Passo Fundo (Fig. 1) has demarcation of urban and rural areas. According to the Brazilian Institute of Geographic and Statistics (IBGE), 11.02% of the territory consists of the urban area, where it concentrates 97.14% of the total population. The rural area covers 88.98% of the territory, where 2.86% of the population lives. The total area of 780,317 (IBGE, 2010) is equivalent to 100%, and includes the urban and rural areas on this surface. However, the rural area has 694,326 km² whereas the urban area allocated to the urban perimeter currently represents a surface area of 88,516 km².

In order to conduct this study, land use maps of the municipality of Passo Fundo (RS) were designed by using images taken from the Landsat TM-7 and TM-8

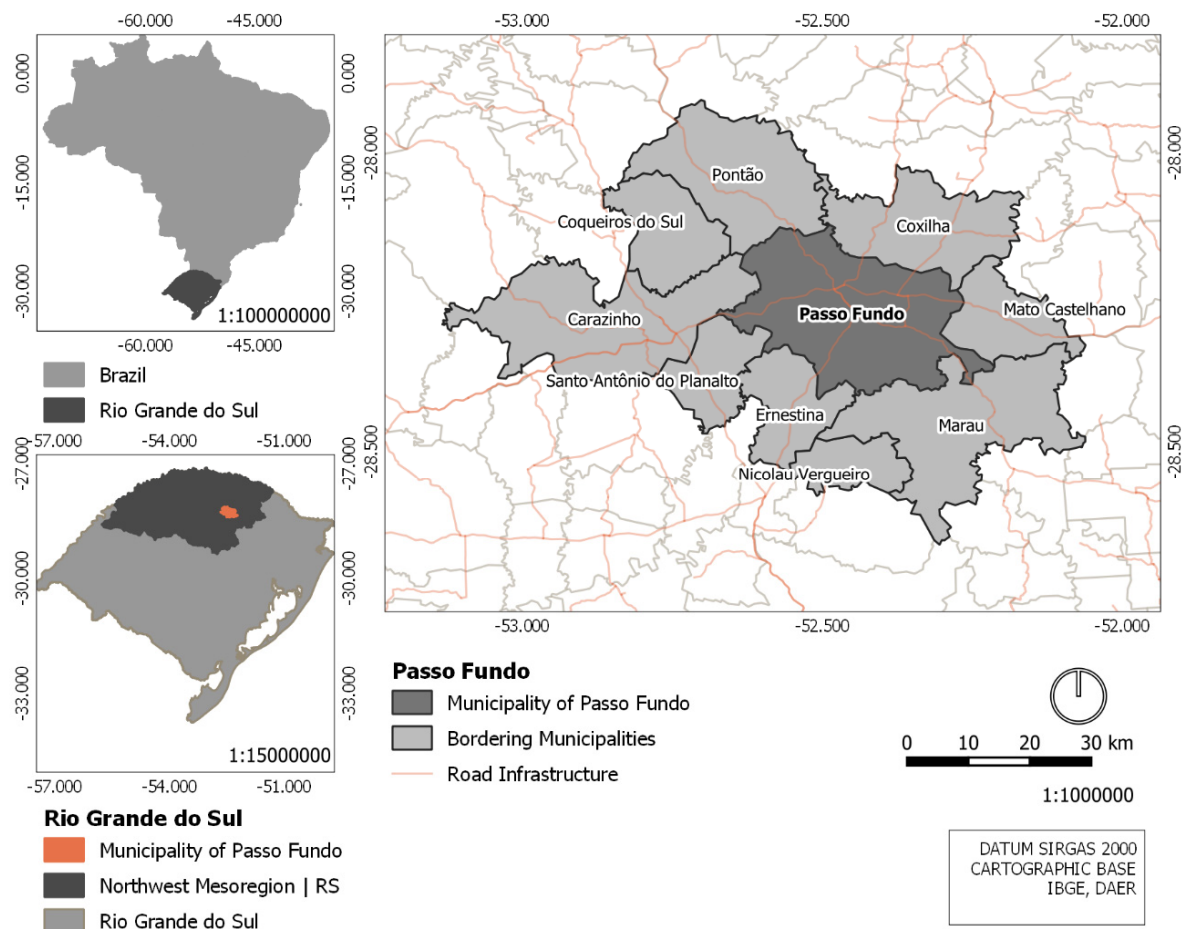


Fig. 1 Location of the Municipality of Passo Fundo/RS, Brazil [11].

satellite, obtained on the United States Geological Survey (USGS) Earth Explorer—QGIS software, (version 2.18) [5]. Two images with different temporalities were used, one for 2001, dated 5 March and the other one for 2020, dated 17 March.

For the design of false-color visualization mosaics, different bands were used according to the satellite's characteristic and specificity. For the Landsat TM-7 satellite, RGB432 band composite was used, whereas for the Landsat TM-8 satellite, RGB654 band composite was used.

The predetermined groups were the following: exposed soil (1), tillage (growing area) (2), forest (3) and water resources (4). These groups were classified through the use of the Dzsaka tool, in QGIS environment, and through the adoption of the Gaussian model, in a supervised manner [12].

The objects resulting from the classifications were two raster files in geotiff format (.tif), which a posteriori, was treated with the Crivo tool, in QGIS environment, which aims to remove raster polygons smaller than a given size limit (in pixels). These mosaics were chosen according to the spatial outline used in this study, which consists the rural area of Passo Fundo. Finally, the files were converted files (shape) into vector format in order to obtain the quantitative data of the groups.

To assess the metrics of the landscape, the group level was considered. Some of the metrics quantify the landscape composite in a quantitative manner. Consequently, the assessment of the landscape metrics was applied to obtain landscape statistics [13]. Subsequently, landscape metrics were calculated in relation to the raster layer [14].

Statistical analysis landscape composite measured land cover (LC), landscape proportion (LP), number of patches (NP), patch density (PD), mean patch area (MnPA), median patch area (MdPA), greatest patch area (GPA), and overall core area (CORE). In this sequence, landscape configuration considered the following measurements for the analysis: edge length (EL), edge density (ED), largest patch index (LPI), fractal dimension index (FDI), mean patch shape ratio (MPSR), like adjacencies (LA), patch cohesion index (PCI), and landscape division (LD).

Through the analysis of the Normalized Difference Vegetation Index (NDVI), the calculation of the NDVI was performed in order to understand the variation estimate of the existing vegetation. The analysis used the Landsat TM 7 satellite, with bands 3-Red, bands 4 and band 5-Near Infrared (NIR). In the case of the Landsat TM 8 satellite, bands 4-Red and bands 5-Near Infrared (NIR) were used [15] (Eq. (1)).

$$NDVI = (NIR - RED) / (NIR + RED) \quad (1)$$

3. Results and Discussions

3.1 Land Use Analysis

The rural landscape is constantly changing. In Figs. 2 and 3, it is possible to compare the two raster files used for the analyses and to note the group called tillage (growing area), according to the landscape matrix.

When analyzing land use and occupation, it is possible to verify in the thematic map (Fig. 4), that, in 2001, the exposed soil group (1) represented 30.16% of the total area, the tillage group (2) represented 47.34%, and as both are related to agro-pastoral production system, they account for 77.49% of the rural area in the municipality of Passo Fundo. The forest group (3) represented 22.27%, and the water resources group (4) consisted of 0.24% of the analyzed area. Through the 2020 land use map (Fig. 5), it can be seen that the exposed soil group (1) corresponds to 31.26% of the analyzed area, and the tillage (growing area) group (2) occupies 46.97% of

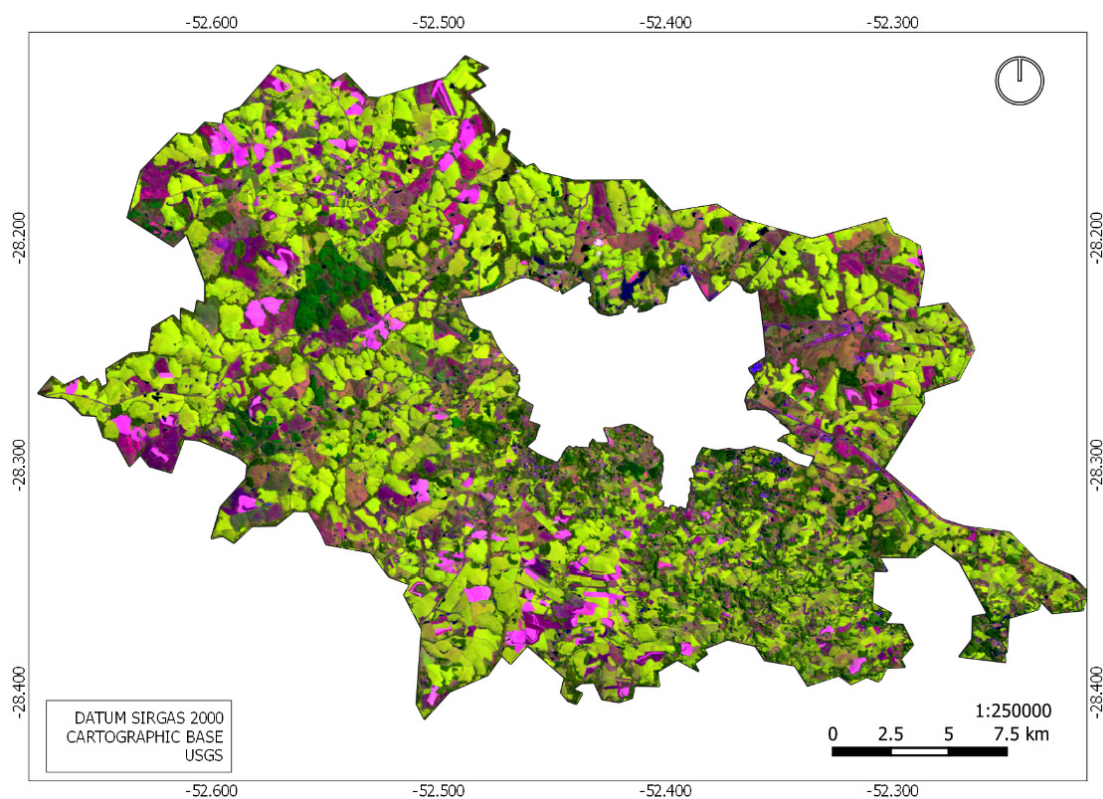


Fig. 2 Comparison of satellite images cropped of the rural perimeter of Passo Fundo/RS-Brazil (2001).

Source: Image taken from the Landsat TM-7 satellite of March 5, 2001 [16], cropped by the IBGE database [11].

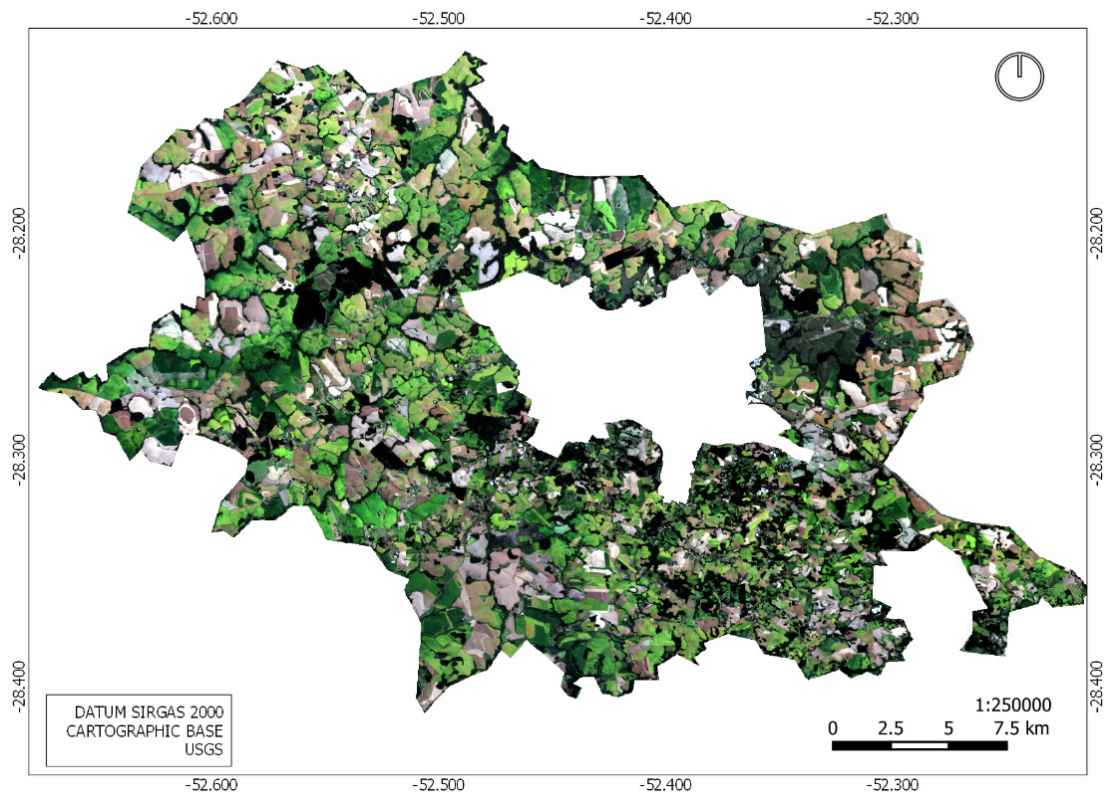


Fig. 3 Comparison of satellite images cropped of the rural perimeter of Passo Fundo/RS-Brazil (2020).
Source: Image taken from the Landsat TM-8 satellite of March 17, 2020 [16] cropped by the IBGE database [11].

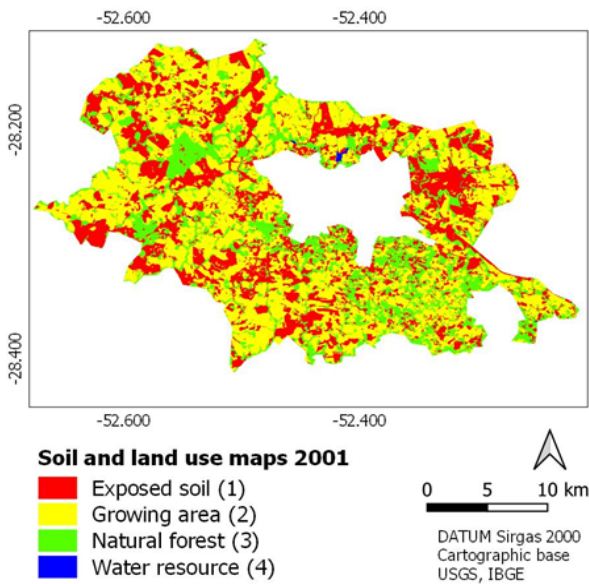


Fig. 4 Land use in 2001.
Source: Image taken from the Landsat TM-7 satellite of March 5, 2001 [16], cropped by the IBGE database [11].

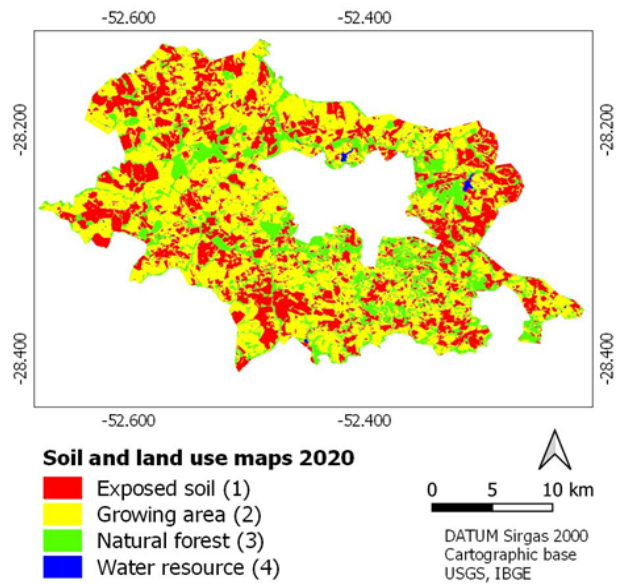


Fig. 5 Land use in 2020.
Source: Image taken from the Landsat TM-8 satellite of March 17, 2020 [16], cropped by the IBGE database [11].

the total area. Forest areas (3) account for 21.46% and water resources (4) account for 0.31%.

From the results obtained, it is possible to better understand the changes in the territory in two decades. The percentage of exposed soil and water resources increased, while the tillage (growing area) and forest areas decreased. The development of technologies such as remote sensing plays an important role in rural and urban areas. In agriculture, it can help reduce food waste and minimize food resources [10] through accurate geospatial diagnostics.

3.2 Analysis of Landscape Composition

The analysis of the composition of the rural landscape of Passo Fundo is carried out through the following metrics: class (group) area (CA), largest patch index (LPI), greatest patch area (GPA), and total core area (TCA). The results obtained, such as land cover (LC), are an interesting tool to differentiate the proportions present in land use. In addition, the analysis is dependent on the researcher's perception and interest in determining the class of analysis and proportion of land cover (PLAND), as these characteristics specify the landscape [17].

The proportion of groups (PLAND) in the rural landscape of Passo Fundo is closely related to agricultural production. In this context, there are two groups that are closely related, namely the exposed soil and the tillage (growing) areas. In 2001, these groups corresponded to 0.290 and 0.476, while in 2020, the proportion was 0.312 and 0.469, respectively, which reveals little significant variation. As for land use related to the forest group, in 2001 the proportion was 0.230, and in 2020 it was 0.214, thus having a decrease of -0.02.

As for the percentage analysis of the largest fragment area (LPI), the group that presents the highest LPI has the most significant interconnectivity between the patches [18]. The connection process can be verified between the tillage (agricultural cultivation) patches, since the percentage of the largest fragment

areas increased from 5.495 in 2001 to 10.812 in 2020, thus having an increase of 96%.

In this context, it is possible to reveal the greatest patch area (GPA) by verifying that the largest patch in the tillage group doubled in size. In addition, the largest forest patch also increased, pointing to a trend towards land use homogenization in the rural area of Passo Fundo.

The total core area (TCA) is defined in the same manner as the core area (CORE) at the patch level, as the core areas are added together. This analysis is more important for the forest group, where the TCA represents 50% of the CA (Class/Group Area) both in 2001 and in 2020.

3.3 Statistical Analysis of Landscape Configuration

The statistical analysis regarding the configuration of the rural landscape of Passo Fundo was structured on the following metrics: Number of Patches (NP), Patch Density (PD), Mean Patch Area (AREA_MN), Median Patch Area (AREA_MD), Total Edge (TE), Edge Density (ED), Fractal Dimension Index (FRAC), Mean Shape Index (MSI), Percentage of Like Adjacencies (PLADJ), Patch Cohesion Index (COHESION) and Landscape Division Index (DIVISION). In this way, the number of patches (NP) and the patch density (PD) were measured in groups. Thus, NP and PD contribute to the explanation of processes related to landscape fragmentation, which is an important ecological process [17].

Through the patch density (PD), the forest group passed through the process of homogenization and densification, since the number of patches reduced by 15%, thus demonstrating an increase from 2001 to 2020 by 92%. This phenomenon can be justified by the increase in agricultural mechanization.

On the other hand, it was found that the perimeter of the urban edge was more intense in the tillage group, with an increase of 22%, and that the other groups showed a variation of less than 5%. The forest group in relation to the decrease in total edge length

(EL) and edge density (ED) showed results that demonstrate the decrease in number of small size fragments, which indicate a great edge effect [18]. In this matter, since the patches are the basic component for landscape analysis, the average size of the patches (AREA_MN) does not show how the distribution of patches occurs and it is not possible to understand the context of the patches [17].

The groups demonstrate a significant variation in the AREA_MN values. As for the temporal comparison, the exposed soil group presented an area of 32% larger than in 2001, and the forest areas showed an increase in the average value of 15%, thus demonstrating how this theme has been improved in Passo Fundo.

The analysis of the fractal dimension index (FRAC), which is based on the perimeter area and quantifies the complexity degree of the flat shapes, showed that the average theoretical limits correspond between 1 and 2, with the fractal dimension varying from 1, which indicates relatively simple shapes, to 2, which indicates more complex and convoluted shapes.

Mean shape index (MSI) analysis refers to the ratio between the perimeter of a patch and the perimeter of the simplest patch in the same group and measures the complexity of the shape. The average complexity of the patch shape (shape geometry), whose values are equal to 1 when the patch has been compacted to the maximum and can increase with no limits, as the shape of the patch becomes more irregular [19]. These values of the exposed soil group decreased from 1.104 in 2001, to 1.069 in 2020, demonstrating aggregation tendency due to the increase in exposed soil. The values of the (tillage) cultivation areas were 0.518 in 2001 and they increased to 0.634 in 2020, which indicates irregularity and loss of patch contiguity, whereas the forest group showed low variation.

In relation to the degree of connectivity, Percentage of Like Adjacencies (PLADJ) was defined by the metric that calculates how similar pixels are

aggregated. Thus, it is clear that agricultural activities are related to (tillage) cultivation areas and exposed soil, which represent the highest index of connectivity. However, the forest group corresponds to 0.74 which is also considered high. The landscape is characterized by homogeneity in the relationship between these two groups.

The landscape division index (DIVISION), defined by the probability that two locations chosen randomly in the landscape under investigation, which is located in the same undissected area, can verify the heterogeneity of the studied landscape through these indices.

3.4 NDVI Analysis

The normalized difference vegetation index (NDVI) allowed carrying out an assessment of the vegetation cover. Thus, it could be verified that for March 2001 the rural area of Passo Fundo had a high NDVI index (Fig. 6). Fig. 7 represents the NDVI index equally for March; however it was possible to observe lower NDVI values for 2020. As the coefficient of variation (CV) analyzes dispersion in relative terms, the lower the value of the CV, the more homogeneous the analyzed data are. The NDVI for 2001 represents 20.47% and for 2020 it was 30.91%, which corresponds to a very high variability.

The NDVI values for 2001 were higher, as they corresponded to 0.778, and for 2020 they corresponded to 0.339. The coefficient of variation (CV) for 2001 was 0.2047 and for 2020 it was 0.3091. Thus, the highest frequency of pixels for 2001 corresponded in NDVI values, from 0.8 to 1.0 with a high concentration of vegetation cover. However, for 2020, the highest pixel frequency between the NDVI values ranged from 0.3 to 0.45, demonstrating the decrease in vegetation in relation to 2001, which may indicate the following processes: the decrease in the forest surface, the temporal change related to agro-pastoral production, or periods of severe drought.

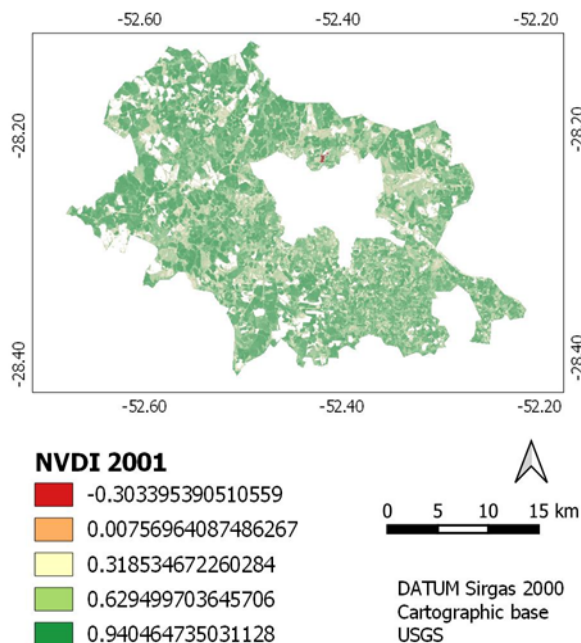


Fig. 6 NDVI for 2001.

Source: Image taken from the Landsat TM-7 satellite of March 5, 2001 [16], cropped by the IBGE database [11].

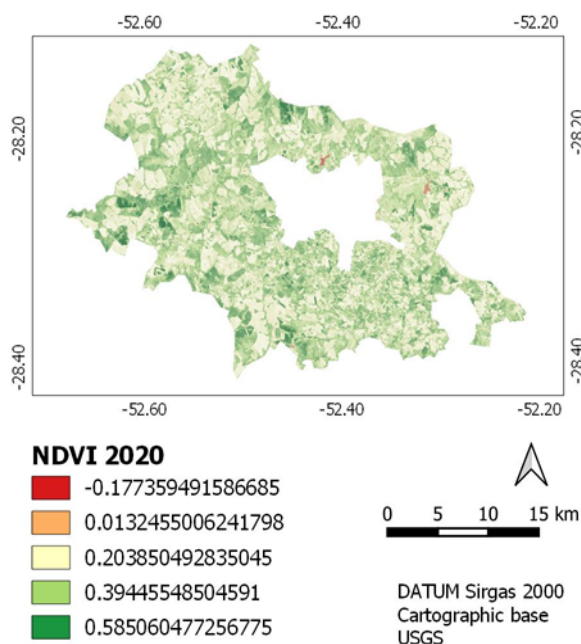


Fig. 7 NDVI for 2020.

Source: Image taken from the Landsat TM-7 satellite of March 5, 2001 [16], cropped by the IBGE database [11].

4. Conclusions

The applied methods in this study were efficient to understand the variations in land use. Thus, it is suggested to apply them at different land use studies

in order to design public policies related to environmental protection.

This study revealed the percentage of areas with the largest fragment size, from 5,495 in 2001, to 10,812 in 2020, with an increase of 96%. Thus, there is a need to monitor the loss of vegetation in the municipality of Passo Fundo.

When observing the NDVI peaks, there is a gradual decrease in land use for agro-pastoral, and lower occurrence of exposed soil. In this analysis, it is clear that there is a significant difference between the two periods analyzed regarding the concentration of vegetation cover in 2001 and in 2020. This study strongly suggests the creation of an environmental protection and recovery plan for the municipality of Passo Fundo.

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