

Soil use and occupation in Caracol Settlement: a multitemporal assessment using remote sensing and geoprocessing techniques

Uso e ocupação do solo no Assentamento Caracol: uma avaliação multitemporal utilizando técnicas de sensoriamento remoto e geoprocessamento

Uso y ocupación del suelo en el Assentamento Caracol: una evaluación multitemporal utilizando técnicas de detección remota y geoprosesamiento

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Abstract

This study focused on the application of remote sensing and geoprocessing techniques to quantify the agroecological use of Caracol settlement area in order to quantify the vegetated areas, as well as the use and occupation of the soil in the years 2000, 2010 and 2020, in the months of May of each year. To achieve the objectives, computational tools (Quantum GIS software) were used, as well as data from Landsat 5 and 8 satellites, bands 3 and 4, 4 and 5 respectively. Vector data from the database of the Brazilian Institute of Geography and Statistics (IBGE), a Digital Elevation Model (DEM), from *the United States Geological Survey* (USGS/NASA) for evaluation of the watersheds were also used. For vegetation analysis, as well as temporal evolution, the Normalized Difference Vegetation Index (NDVI) was used, with this it was possible to evaluate by means of thematic maps and tables

containing the quantification and classification of vegetation and soil cover. It was evident in the present study that there were significant changes in the vegetation landscape over two decades, through anthropic activity by settled families, that were responsible for such changes in the use and soil cover of Caracol settlement.

Keywords: Normalized difference vegetation index (NDVI); Use of soil; Landsat; Settlement; Remote sensing.

Resumo

Este estudo se deteve na aplicação de técnicas de sensoriamento remoto e geoprocessamento para a quantificação do uso agroecológico da área do assentamento Caracol com intuito de quantificar as áreas vegetadas, bem como o uso e ocupação do solo nos anos de 2000, 2010 e 2020, nos meses de maio de cada ano. Para o alcance dos objetivos, foram utilizadas ferramentas computacionais (*software* Quantun Gis), além de dados dos satélites Landsat 5 e 8, bandas 3 e 4, 4 e 5 respectivamente. Foram utilizados também dados vetoriais da base de dados do Instituto Brasileiro de Geografia e Estatística (IBGE), Modelo de Elevação Digital (MDE), do *United States Geological Survey* (USGS/NASA) para avaliação das bacias hidrográficas. Para análise da vegetação, bem como a evolução temporal, foi utilizado o Índice de Vegetação por Diferença Normalizada (NDVI), com isso foi possível avaliar por meio de mapas temáticos e tabelas contendo a quantificação e classificação da vegetação e cobertura do solo. Ficou evidente no presente estudo que houve mudanças significativas na paisagem da vegetação no decorrer de duas décadas, isso mediante a atividade antrópica por família assentadas, as quais foram responsáveis por tais modificações no uso e cobertura do solo do Assentamento Caracol.

Palavras-chave: Índice de vegetação por diferença normalizada (NDVI); Uso do solo; Landsat; Assentamento; Sensoriamento remoto.

Resumen

Este estudio se centró en la aplicación de técnicas de teledetección y geoprosesamiento para cuantificar el uso agroecológico del área de asentamiento de Caracol con el fin de cuantificar las áreas vegetadas, así como el uso y ocupación del suelo los días 25, 21 y 16 de mayo. 2000, 2010 y 2020 respectivamente. Para lograr los objetivos se utilizaron herramientas computacionales (*software* Quantun Gis), además de datos de los satélites Landsat 5 y 8, bandas 3 y 4, 4 y 5 respectivamente. También se utilizaron datos vectoriales de la base de datos del *Instituto Brasileiro de Geografía e Estatística* (IBGE), Modelo Digital de Elevación

(MDE), del *United States Geological Survey* (USGS/NASA) para la evaluación de las cuencas hidrográficas. Para el análisis de la vegetación, así como la evolución temporal, se utilizó el Índice de Vegetación de Diferencia Normalizada (NDVI), con este se pudo evaluar mediante mapas temáticos y tablas que contienen la cuantificación y clasificación de la vegetación y cobertura del suelo. En el presente estudio se evidenció que hubo cambios significativos en el paisaje vegetal a lo largo de dos décadas, esto a través de la actividad antrópica de las familias asentadas, responsables de tales cambios en el uso y cobertura del suelo del *Assentamento Caracol*.

Palabras clave: Índice de Vegetación de Diferencia Normalizada (NDVI); Uso del suelo; Landsat; Asentamiento; Detección Remota.

1. Introduction

In Mato Grosso do Sul-MS, there is a total of 203 federal rural settlement projects, with a total area of approximately 697,688 hectares, with an amount of 43,174 families. These rural settlements exist in 54 of the 78 cities of the state of Mato Grosso do Sul (INCRA, 2012).

The use of land for food production by small producers of family farming has become the object of scientific research in various fields of knowledge. Before such context, the United Nations Food and Agriculture Organization (FAO) believes that family agriculture plays an important role for society, which has great potential to ensure food demand to meet the needs of society in Brazil, as well as in the world (FAO, 2012).

Deforestation, the loss of biodiversity due to the irregular use of soil, end up causing the ecosystems degradation. Silva (2011), believes that such impacts on the environment are caused by the removal of native vegetation and by the implementation of disordered agricultural ecosystems. As well as inadequate soil management, monoculture and extensive use of pesticides, which can affect and harm the forest environment and the socioeconomic aspects of a region or locality (Rezende *et al.*, 2013).

Space-temporal changes in soil and vegetation use are caused by the influence between natural mechanisms and anthropic factors. As reported by Forman (1995), human activities are determined as a decisive cause of changes in the forest landscape, however, soil deformation, as well as its occupation is closely associated with climate issues and the use of soil through agricultural activity. In this area, few studies focused on the interaction between changes in soil use and structural characteristics of the landscape (PAN *et al.*, 1999).

The emergence of remote sensing technology and the development of computing enabled geographers (and other professionals) to process more and more information related to the study of vegetation and soil status through satellite data. Such technologies made it possible to acquire, represent and analyze geospatial information, and the data obtained became important tools for many studies relevant to the soil use and cover (Dambrós, 2020).

In recent decades, the use of remote sensing technology has been widely used in studies and analyzes of vegetation conditions and their spatial-temporal variabilities, allowing mapping through digital classification of geospatial data. According to Santos (2018), the monitoring of land use and cover through sensory techniques is an important activity and can be used to estimate and quantify the transformations that occurred in soil cover through geoprocessing procedures, in order to obtain information that may assist in mapping climatic, environmental, and soil use and cover scenarios and indicators. Thus, equipped with satellite technologies, it is possible to investigate practices such as inadequate management of deforestation processes and adopt strategies to achieve sustainability, as well as decision making.

The vegetation dynamics in recent years have been studied worldwide with the aid of remote sensing tools and geoprocessing techniques, subsidized by the use of images captured by remote sensors coupled to satellites for image of the earth's surface (Lima & Almeida, 2017).

Remote sensing tools contribute to studies of the vegetation health flexibility, since they allow to characterize the spatial and temporal variability of biophysical parameters, quantifying the electromagnetic energy reflected through the plants' chlorophyll (Mazzetto *et al.*, 2010). Thus, sensory-derived satellite data such as the *Normalized difference Vegetation Index* (NDVI) is often used to evaluate vegetation dynamics. Taskos *et al.* (2015) mention that NDVI relates the reflectance in the infrared and near infrared wavelengths, being considered an indicator of green biomass accumulation, as well as in the multi-temporal analysis of the changes in soil cover as to its use.

During the years 2000 to 2020 (that is, two decades), changes occurred in the floristic landscape in areas of the southwest region of Mato Grosso do Sul, especially in areas that comprise rural settlements, since these properties are intended for the planting of agriculture, and therefore, these areas in general deforestations occur, resulting from anthropic activity, causing soil erosion, reduction of native vegetation reserve, among other processes inherent to population support activities. Other associated factors are the severe climatic conditions that also contribute to the vegetation dynamics over the years, although this, in a gradual way in

the face of this context, changes in plant cover are noticeable through human activity interference in these regions, for this reason, this study makes the following inquiry: Which factors contributed to the gradual change of tree cover in Caracol settlement between 2000, 2010 and 2020?

The research was supported, at the end of the hypothesis, that there were significant changes in vegetation in the locality of Caracol settlement during two decades (2000, 2010 and 2020), due to the anthropic action, possible events of prolonged drought, agricultural activities, as well as burning activity among other associated factors. The choice of the period of the years 2000, 2010 and 2020 was aimed at analyzing the changes in the vegetation over 20 years, in order to verify the behavior in the use and occupation of the soil before and after the Caracol settlement implementation.

The research was carried out with the objective of identifying, by means of remote sensing and geoprocessing techniques, the vegetation dynamics, regarding its increase or decrease in wooded areas, and identifying which factors contributed to such changes, making a comparison, based on the years 2000, 2010 and 2020, in Caracol rural settlement, in the city of Bela Vista, Mato Grosso do Sul, Brazil.

2. Material and Methods

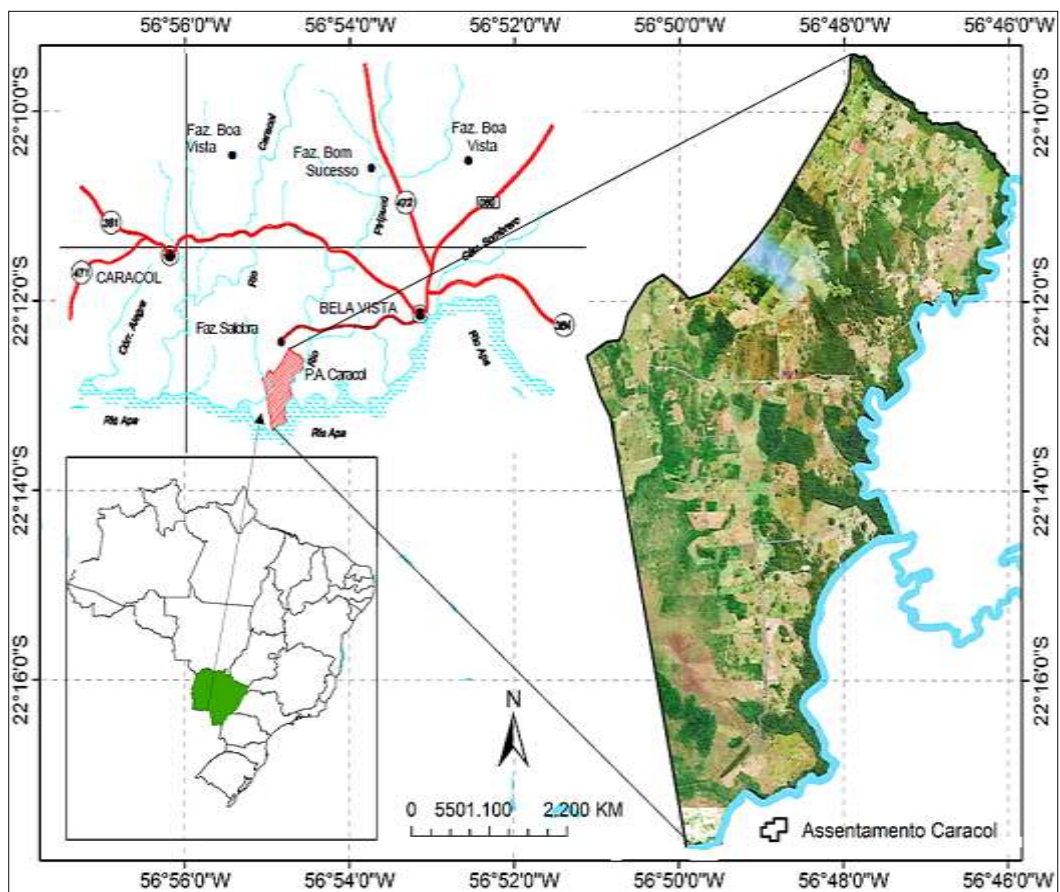
The present study had as methodological criteria, qualitative and quantitative approaches, using conceptual methods to analyze the objectives proposed, and at the same time, on exploratory approaches, that is, literary-based approaches that relate to the proposed theme, with the purpose of analyzing in various sources of research, such as scientific articles and books scientific concepts and papers associated with the context studied.

According to Creswell (2007), the qualitative research technique comes from an epistemic model, which is based on the constructivism point of view (that is, on the multiple meanings of personal experience, on the meaning of social structures and on the development of a research theory) or on a proposition/communicative perspective (that is, one aspect about investigative issues). In this type of research, the researcher collects the data with the objective of developing specific topics based on the data collected.

2.1 Characterization Of The Studied Area

The research was carried out in the micro-region of Bodoquena in the state of Mato Grosso do Sul, more specifically, at Caracol settlement (Figure 1), which is inserted in the municipality of Bela Vista, and situated geographically in the reference points of latitude and longitude (Lat: 21° 53' 37,7" S; Lon: 56 34'01,32"), 197 meters above the sea level. According to the 2010 census, the population of Bela Vista was 24,629 inhabitants, has an area of approximately 4,892.6 km² of territorial extension, and a population density of 5 inhabitants/km² (IBGE, 2010).

Figure 1 - Location of Caracol Settlement.



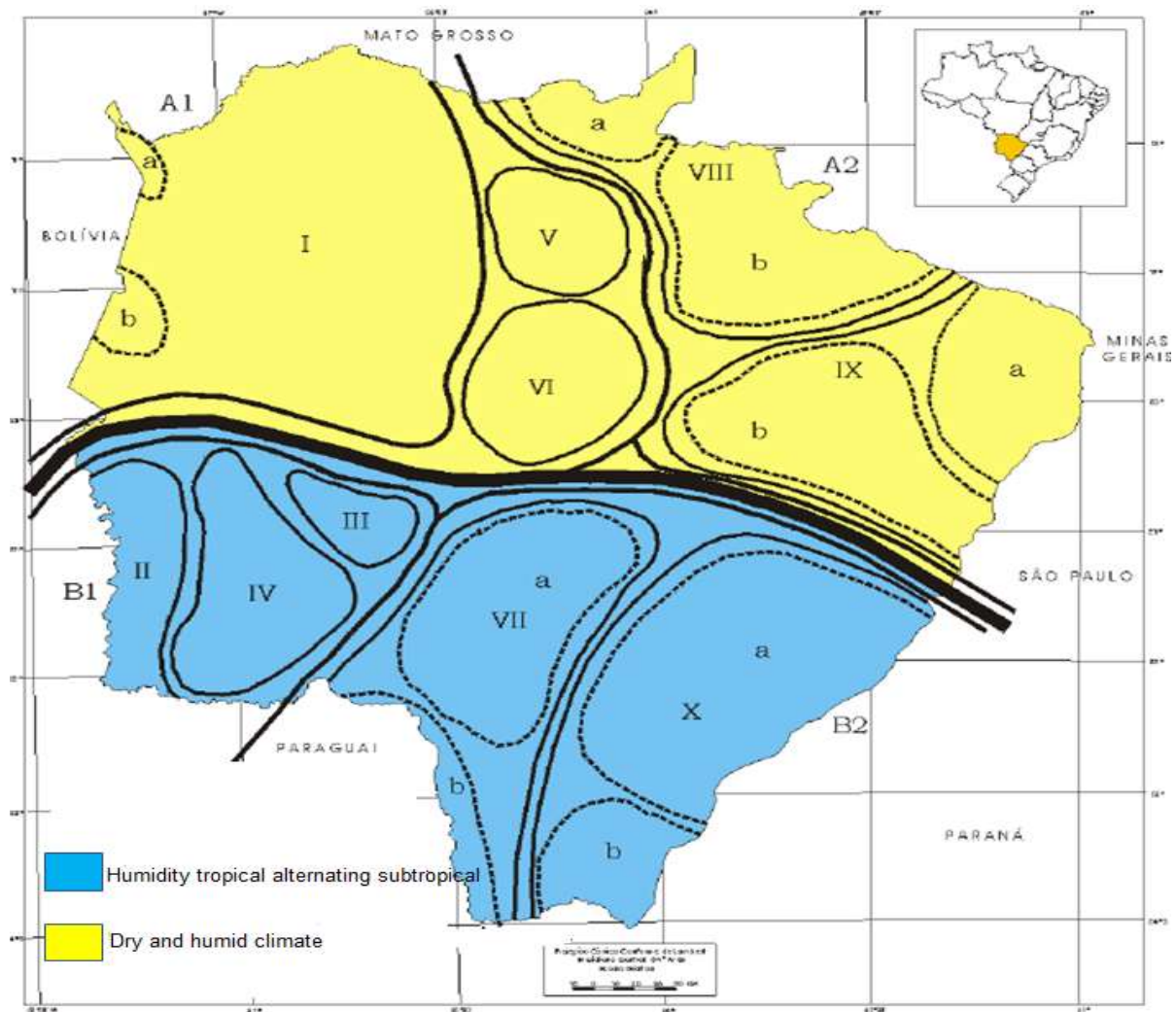
Source: Authors (2020).

2.1.1 Climatic Characterization of the Municipality of Bela Vista

The state of Mato Grosso do Sul is located in a climate transition zone (Figure 2), for this reason, the weather and climate of the region is influenced by mass air currents from low and high latitudes, The so-called polar air mass and air masses of equatorial origin, besides

being located in the moisture corridor coming from the Amazon region, these climatic characteristics show that the state of Mato Grosso do Sul is under the influence of accentuated thermal amplitudes during the year (EMBRAPA, 2013).

Figure 2 - Climate classification map of the state of Mato Grosso do Sul.



Source: Zavattini (2009).

According to Köppen climate classification, the climate covering the region where the Caracol settlement is located is classified in the sub-type category Cfa – humid subtropical (KÖPPEN, 1928). This microclimate profile is being represented by Figure 2, in blue color, in this case, where Caracol settlement is located, more precisely in the micro region of Bodoquena Plateau, identified on the map (Figure 2), by the Greek number IV. The hottest month has a temperature above 25°C and the driest month with a maximum rainfall of 30 mm. It belongs to the tropical sub-humid, with rainy season in the summer and dry in the winter, and approximately 75% of the rains occur with a higher predominance between October and

April, while the average temperature varies around 24°C. The months with the lowest rainfall index are the months between June and August, with an average temperature of 20 °C and a minimum average temperature between 10 °C to 12 °C (EMBRAPA, 2013).

2.1.2 Dataset used

In order to achieve the objectives proposed research, data acquisition was necessary in different sources, both national and international.

Data from *Land Remote Sensing Satellite-Landsat 5, Thematic Mapper (TM)* sensor and Landsat 8, *Operational Land Imager (OLI)* sensor were used, which are managed by National Aeronautical and Space Administration (NASA). OLI is a spectral sensor coupled to Landsat 8, which has 9 multispectral bands with 30 meters resolution operating in bands 1 to 7 and 9. As seen, the geospatial data used in this research originated from the *Thematic Mapper (TM) sensor*, operated in the wavelength range from 0.45 to 2.35µm of Landsat 5. Spatial resolution 30 x 30 m, and cover area is 185 x 185 km. Landsat 8 was launched in 2013 and is currently in operation, whereas the TM sensor has been inactive since November 22nd, 2011.

Geospatial data were acquired through the *Earth Explorer (EE)* platform, which is a research tool for *online* data acquisition, which was developed by *the United States Geological Survey (USGS/NASA)*. EE provides supports to data searching from different satellites, and can be accessed through <https://earthexplorer.usgs.gov/>.

2.1.3 Data

Data from the spectral bands 3 (0.63-0.69µm) and 4 (0.76-0.90µm), from *Thematic Mapper (TM) sensor*, from the Landsat 5 satellite and the *Operational Land Imager (OLI)* of Landsat 8 were cataloged to analyze the vegetation dynamics, on the dates of 25th, 21st and 16th of May of the years 2000, 2010 and 2020 respectively.

The spectral bands used were bands 3 and 4, of Landsat 5, while for OLI sensor of Landsat 8, bands 4 (0.64-0.67µm) and 5 (0.85-0.88µm) were used, on May 16th, 2020. Therefore, the use of Landsat satellites 5 and 8 is due to the study temporal analysis, since Landsat 5 only covers the years 2000 and 2010, and Landsat 8 was used for the images acquisition for 2020, since Landsat 5 went into inactivity on November 22nd, 2011.

It is worth noting that satellite images, as highlighted by Lima et al. (2020) provide greater benefits compared to other types of data, because satellite management agencies make historical series of data available free of charge and can be acquired remotely using only the Internet. Among the various types of data, it is important to highlight vegetation data, such as those used in this article.

2.1.4 Vector data

The vector database of the data in *shapefile* format and .shp extension for the analysis of the morphological, hydrogeological environment, for pedological and phytological characterization of Caracol settlement, were extracted from the Brazilian Institute of Geography and Statistics (IBGE) database, available free of charge at: <https://www.ibge.gov.br/geociencias/downloads-geociencias.html>.

2.1.5 Digital Elevation Model (DEM) data

The data used for delimiting the watersheds were made with data from the Sentinel satellite 1A, which is part of Copernicus mission of the European Space Agency (ESA) and are used to observe and monitor phenomena on the earth surface. Its data is distributed free of charge and any registered user can download it from the Internet on a specific site maintained by ESA (Servelloe *et al.*, 2015).

Digital elevation data for reading the physical conditions of the watersheds that are located in Caracol settlement region has a spatial resolution of 12.5 m. Such information is often made available free of charge on platforms available on the internet free of charge. These data were acquired in *geotiff format*, soon after Qgis 3.2 software was used for clipping and highlighting of the area that involves the Caracol settlement, with the aim of characterizing the influence area of the settlement watersheds.

2.2 Software Used

The open-source distribution software, Quantum GIS, version 3.2 was used to perform this research. Quantu GIS or simply Qgis is a software that allows to perform processing, analysis, visualization and editing of spatial data in various formats. Qgis also

allows the creation of multi-layer maps using various cartographic projections used worldwide.

Qgis is a geoprocessing software with potential for generating information in the form of thematic maps, which can be used for various scientific purposes, such as: environmental analysis, agriculture, study of the vegetation dynamics behavior, study of urban areas, population analysis, among others (Pejovićet *et al.*, 2014).

2.3 Methods

The term method and methodological processes, according to Collis and Hussey (2005) are often used as synonyms. In view of this, Collis & Hussey (2005) pointed out that the methodology refers to the general research method, from the theoretical basis to the data collection and analysis, while the method refers only to the various methods of data collection and analysis. However, since the research objects and the analysis dimensions are complex to quantify, a research method with epistemic mold has been selected.

2.4 NDVI Calculation for Vegetation Mapping

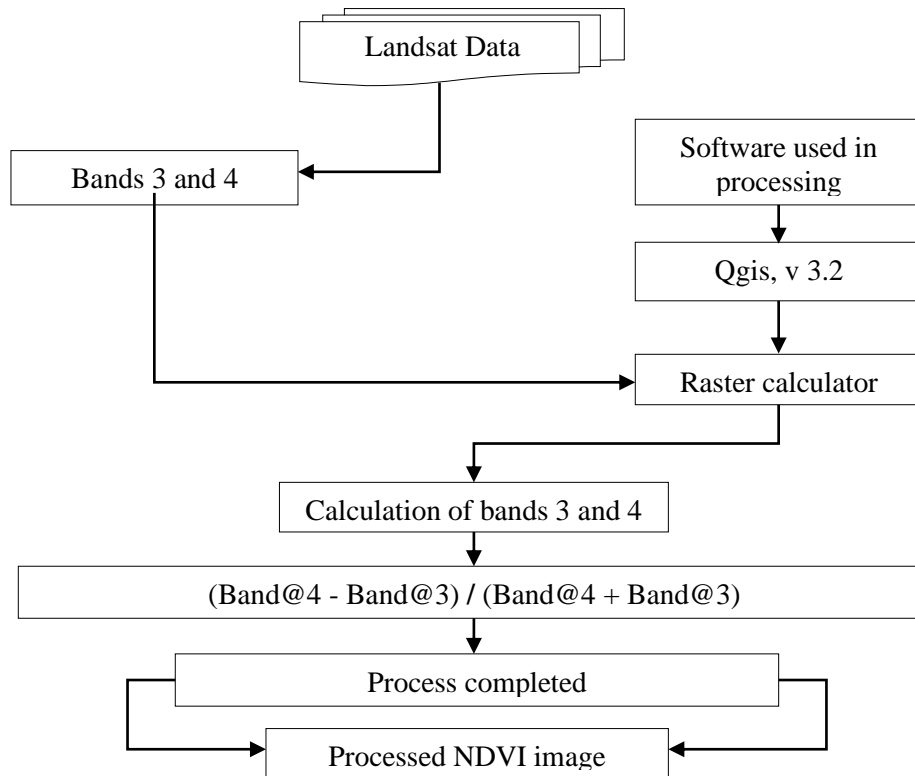
The NDVI calculation was made from the difference between the reflectance of band 4 (near infrared) and band 3 (visible red) divided by the sum of the reflectance of these two bands, according to Equation 1. The results of this fractionation range from -1 to 1. In the red band, chlorophyll absorbs solar energy and results in low reflectivity, while in the near infrared band, the leaves inner morphology and the vegetation structure cause high reflectivity of the incident solar energy (Lourenco & Ladim, 2004, p. 2). Therefore, the NDVI calculation meets the following mathematical criteria:

$$NDVI = \frac{(\rho_{IV} - \rho_V)}{(\rho_{IV} + \rho_V)} \quad (\text{Eq. 1}).$$

Where: ρ_{IV} is the near infrared reflectance, in the spectral range between 0.76 to 0.90 μm ; ρ_V is the reflectance of the red visible spectrum 0.63 to 0.69 μm of the Landsat 5 satellite; near infrared 0.64 to 0.67 μm and reflectance of the red visible spectrum 0.85 to 0.88 μm Landsat 8. These values refer to TM 4 (*Red-IR*) and 3 (*Near Infrared-NIR*) bands of the Landsat 5

satellite. For Landsat 8 satellite the bands refer to bands 4 (*Red-IR*) and band 5 (*Near Infrared-NIR*). The processing of these spectral bands is detailed in Figure 3:

Figure 3 - Procedures for calculating NDVI.



Source: Authors (2020).

2.5 Geoprocessing Software Qgis Application, Release 3.2

With Qgis software, it was possible to delimit the study area through a polygon shape of Caracol settlement, in order to make a demarcation of the study area specifying the analysis area. After this delimitation, precise shapes were generated from *the raster layers* (NDVI image) and the corresponding values were extracted for each *pixel value* of Caracol Settlement area.

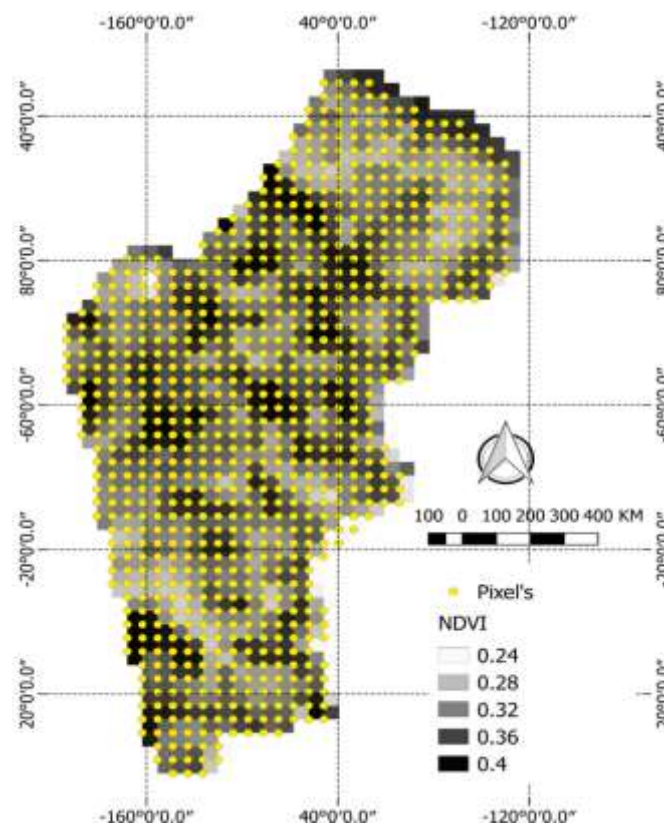
The aim of quantifying *the pixels* was to quantitatively delimit the settlement micro areas, with the aim of mapping the areas with the highest degree of environmental degradation, as well as verifying the areas with the highest vegetative index. This is possible, because it is known that NDVI is a dimensionless measure, ranging from -1 to 1, and the closer to -1 indicates that the vegetation is in severe dry state, exposed soil or water bodies, and the closer to 1, it indicates that these areas that have pixels above 0.5 are areas with dense/healthy vegetation, and as this index tends to approach 1, it is an indication of good

health conditions of vegetation, being characterized by a dense tree volume with a characteristic of preserved area.

By using the Qgis processing tool called *Add raster value to Point*, it was necessary to create the dots *shapefile*, as it can be seen in Figure 4, and thus the NDVI values of the images in *GeoTIFF format* can be exported to a text file. In this case, *the character-separated values (CSV)* were used here, from there it was possible to exploit the data in table form for further analysis.

For extraction, the *Point sampling Tool* application was used. After being extracted the NDVI values were imported into spreadsheets for creating tables for further analysis, as it can be seen later. Using *the Point Samplin Tool* application.

Figure 4 - Pixel location mesh.

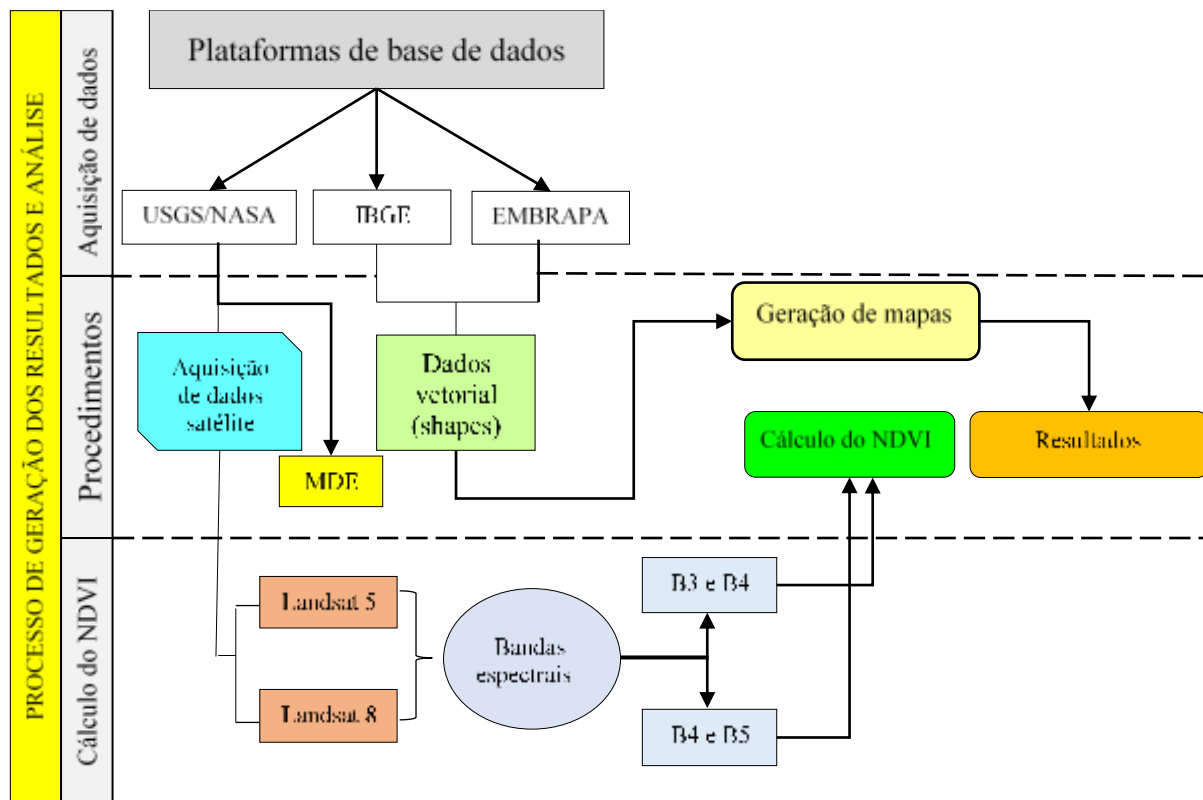


Source: Authors (2020).

2.6 Analysis Procedures

To perform quantitative and qualitative analysis, the method adopted sought to synthesize the information processed in a gram flow for better understanding. Therefore, the methodology followed certain steps as shown in Figure 5.

Figure 5 - Flowchart showing the research methodological processes.

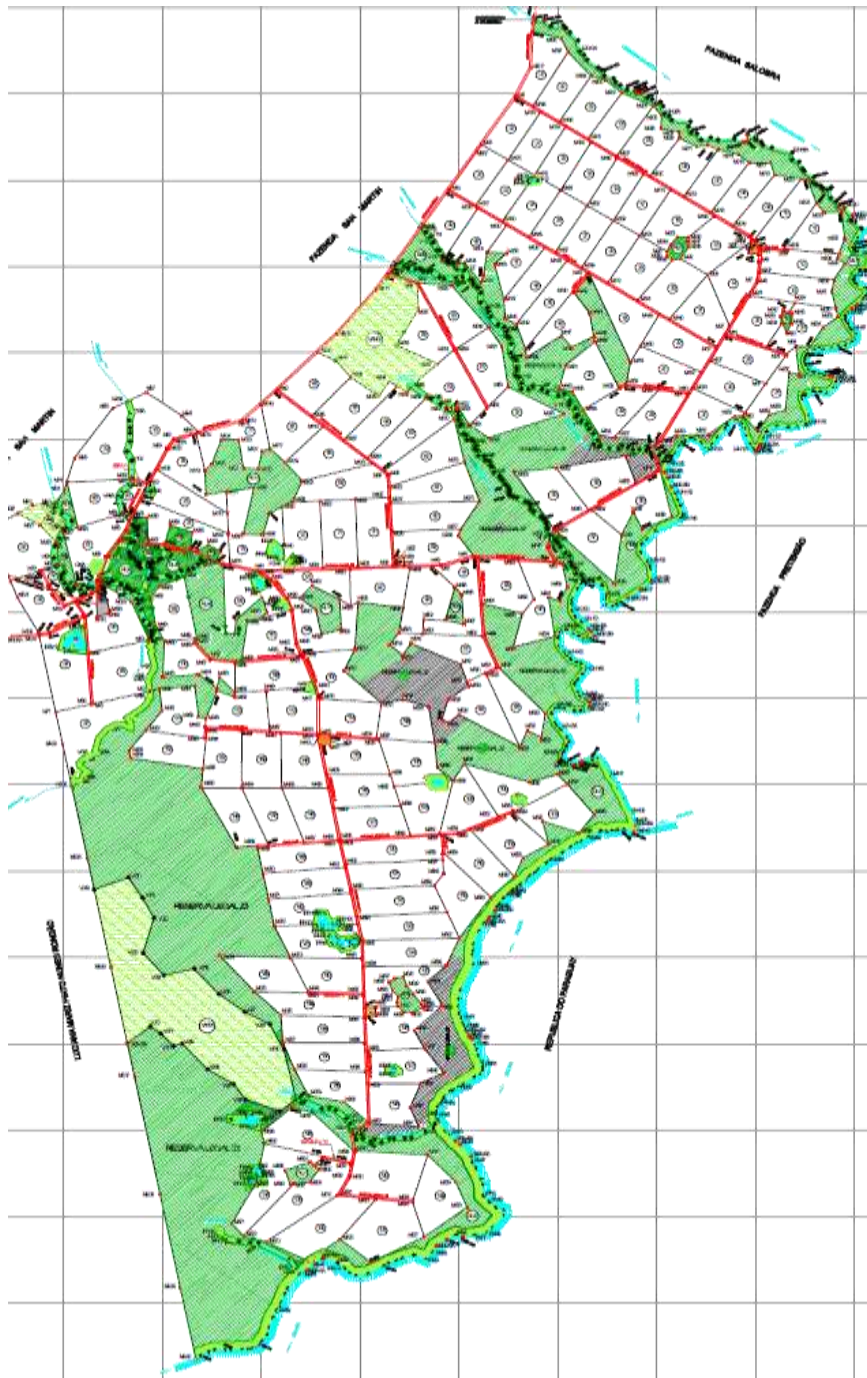


Source: Adapted from Santos (2018).

3. Results and Discussion

Caracol Settlement was created and approved by INCRA on August 11th, 1998 and can accommodate 152 families. Until 2018 there were 152 settlements, occupying an area equivalent to 6,326.58 hectares (INCRA, 2018). Figure 6 shows details concerning the use and of the total spatial occupation of Caracol Settlement.

Figure 6 - Caracol Settlement sketch.



Source: INCRA (2017).

Of 6,326.40 ha of Caracol Settlement, according to a survey of INCRA in 2017, 1,655.24 ha are of preserved reserve area, as shown in figure 6 indicated by the green color, the other areas are distributed among pasture, water bodies and anthropized areas (figure 5, highlighted in white), these areas are intended for agriculture and other activities focused on human handling and exploitation.

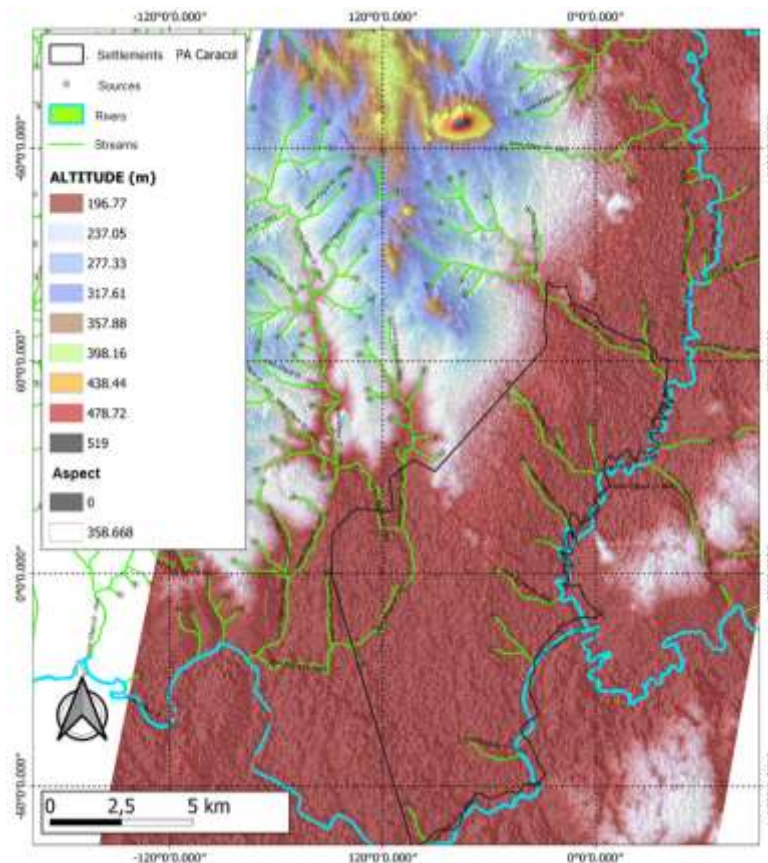
3.1. Analysis of the Relief, Watersheds and Use and Occupation of Soil

3.1.1 Relief and Surrounding Hydrography

Caracol Settlement is under the influence of Apa river watershed on a plain with predominance of pasture and anthropized areas.

This type of plain and soil conditions presents in their physical form little permeability, depth and high-water retention capacity, presence or absence of dense layers and gravel, undulating conditions, low slope and small undulations and vegetation cover, which favors the rain water retention. Figure 7 shows the relief physical characteristics using the Digital Elevation Model (DEM) map.

Figure 7 - Relief characterization and hydrographic watersheds by means of DEM.



Source: Authors (2020).

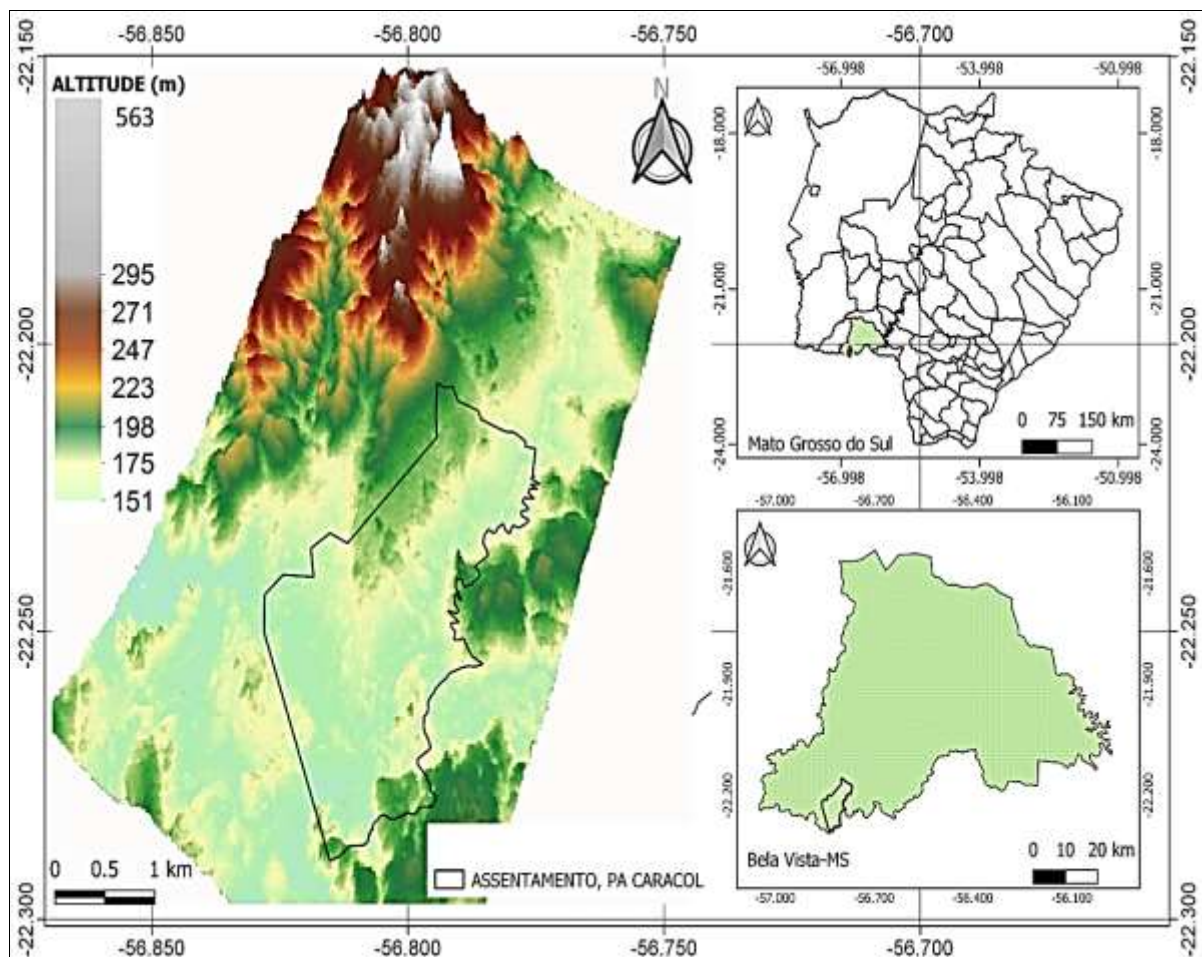
Figures 7 and 8 present a sample of the physical characteristics of Apa river watershed, represented by the green and blue lines. The plain is being represented by brown color, with an altitude of 196.77 meters in relation to the average sea level. The light blue and

yellow colors are between altitudes 300 to 450 meters, while peak heights are signaled in Figure 7 by black color.

Based on what it can be seen in Figure 8, Caracol settlement consists of a rich drainage network inserted in Apa river watersheds connected to several tributaries that contribute to the water volume.

Also, regarding the physical aspects of Caracol settlement relief, Figure 8 shows a three-dimensional panorama based on data from the terrain digital elevation model. In view of Figure 8, it is possible to note that the areas of light blue color comprise the plain areas. In this sense, the settlement is located in a plain region, as it can be seen.

Figure 8 - Digital Elevation Model in 3 dimensions.



Source: Authors (2020).

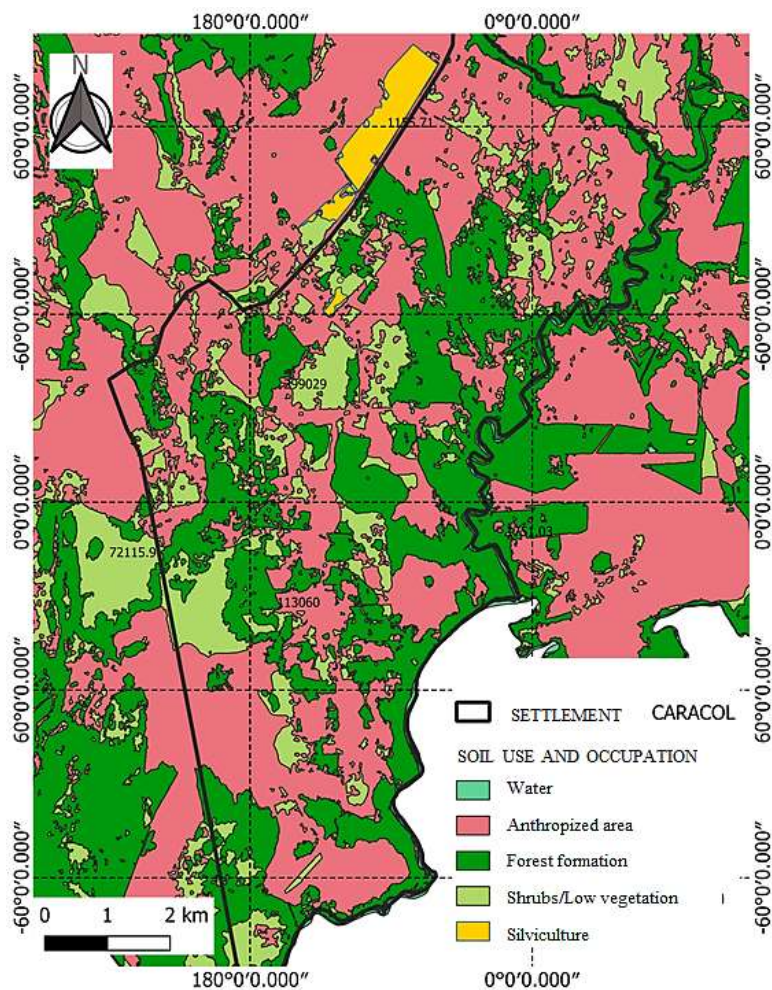
As for geomorphology, Caracol settlement is under an area of relief to the east and west, but the settlement is between two elevations of steep mountains, and has a slope of approximately 21° to the west (SEMADE, 2016). However, the area where 80% of the

Caracol settlement is located is constituted by a flat and clay area, which contributed to the rain water accumulation under the influence of Apa River watershed.

3.2. Soil Use and Occupation

As for the soil use and cover (Figure 9), it can be seen that the surface in its great proportionality consists of anthropogenic areas, highlighted by the pink color.

Figure 9 - Map of soil use and cover.



Source: Authors (2020).

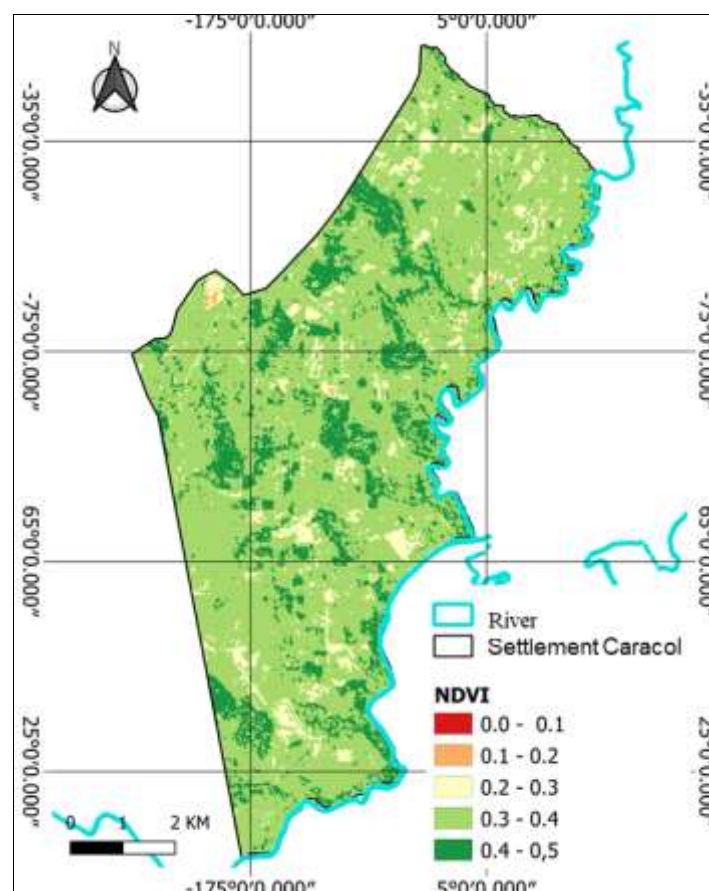
Those are areas intended to family agriculture exploration, animals raising, silviculture, among others smaller proportion agriculture and livestock activities. Another highlight is the permanent preservation areas, which correspond to 1,655 ha of a total of 6,326.40 ha. The areas in light green correspond to areas with shrub vegetation and other species of degraded vegetation.

3.3. Quantification of Vegetation Cover Among the Years 2000, 2010 and 2020

The IBGE technical land use manual is used to determine the categories exposed in the soil considered the most relevant, such as agricultural areas (temporary and permanent crop, pasture and arborization), non-agricultural human area (bare soil) and area category (IBGE, 2006).

Based on these methods, it was possible to evaluate the percentage of the areas with the different species of vegetation cover using the Normalized Difference Vegetation Index (NDVI), using the pixel extraction method taking into account the value for each pixel, obeying the values exposed in each pixel in the image. Figures 10, 11 and 12 show the NDVI results regarding the vegetation health and its respective estimates of vegetation in a qualitative and quantitative way at Caracol settlement for the years 2000, 2010 and 2020 (month May of each year).

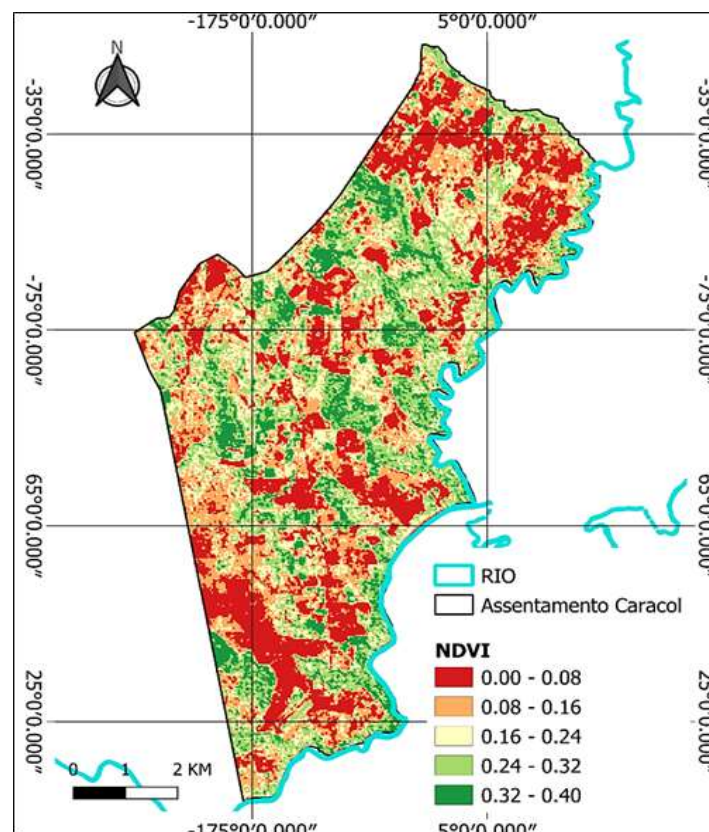
Figure 10 - NDVI, May 25th, 2000.



Source: Authors (2020).

In Figure 10 it is possible to notice that the area of the Caracol Settlement in the year 2000 had the predominance of healthy vegetation, and areas with signs of soil degradation by anthropic influence not yet so marked, as can be seen. In the figure above, it can be seen that the NDVI varied predominantly between 0.3 and 0.5, which indicates that the vegetation was mostly dense vegetation, planted pasture, and/or permanent and intermittent crops. Such characteristics are evidenced due to the color between dark green and light green, as can be seen in figure 10. Figure 11 shows the same characteristics, but in 2010, the Caracol Settlement was already fully occupied by farmers, however, there was already agricultural activity.

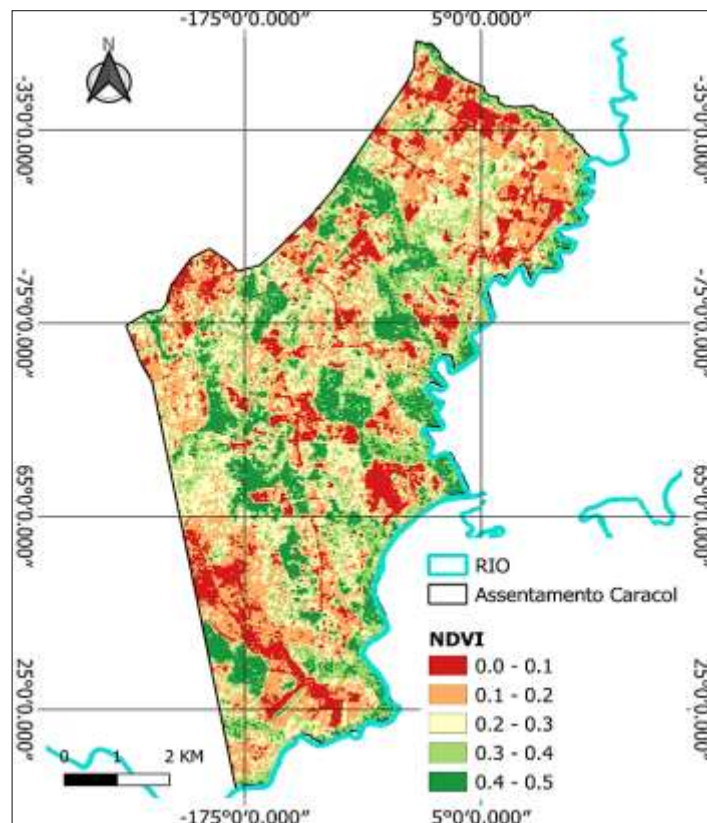
Figure 11 - NDVI, May 21st, 2010.



Source: Authors (2020).

In Figure 11, it can be seen that there has been a significant change in vegetation, which can be evidenced by the NDVI values, as categorized by the colors between red and dark green, and the areas in red, i.e., index between 0.00 and 0.16 (red and orange color) indicates bare soil, dry vegetation, dry pasture, or anthropized areas, due to agricultural activity, among others. It is important to point out that the areas in dark green and light green are the areas of the Settlement where there is still preserved vegetation.

Figure 12 - NDVI, May 16th, 2020.



Source: Authors (2020).

As it can be seen in Figures 10, 11 and 12, it was observed that in the year 2000 the vegetation at Caracol settlement presented a uniformity, that is, little agricultural activity, preserved vegetation, without accidents in the soil. When the year 2010 was observed, it is clear that there were significant changes in the landscape over the years between 2000 and 2010. At another moment, now in 2020, the vegetation index fluctuates in order to respond according to agricultural activity, being a little more uniform in relation to 2000 to 2010, a period where a greater anthropic activity was observed at Caracol settlement.

3.4. Characterization of Soil Use and Cover Based on NDVI

As it can be observed, a selection was made by corresponding pixel values and classified by category of the plant cover characteristic, as shown in Tables 1, 2 and 3. With the pixel values of the NDVI data, it was possible to calculate the areas based on the pixel quantity and its corresponding value as observed in the columns regarding the *Pixel* quantity. In view of this information, it was possible to estimate the value of each area, and thus to perform the plant cover categorization, which in Tables 1, 2 and 3 is represented by “soil

cover”. This, taking into account the total area of the studied region, which is 6,326.58 ha. Soon after, the areas percentages were made according to the pixel values according to Table 1, where it can also be verified in Tables 2 and 3.

Table 1 - Percentage of plant cover, average NDVI year 2000.

Soil cover	NDVI	Pixel quantity	Area (ha)	Area (%)
Exposed soil/Bodies of water	0.0 - 0.1	208	18.72	0.2959
Degraded pasture	0.1 - 0.2	779	70.11	1.1082
Pasture and tree vegetation	0.2 - 0.3	23,094	2078.46	32.8528
	0.3 - 0.4	31,324	2819.16	44.5606
Sparse healthy vegetation (including agriculture)	0.4 - 0.5	4,826	434.34	6.8653
Dense healthy vegetation	0.5 - 06	10,021	901.89	14.2556

Source: Authors (2020).

In the healthy vegetation area, the NDVI analysis in 2000 showed that the area represented 14.25 % of the total area of the study, 6.86 % of the area of sparse vegetation or agriculture, 44.56 % pasture and tree vegetation, 1.1% degraded pasture and only 0.29% was bare soil or bodies of water.

Table 2 - Percentage of plant cover, average NDVI year 2010.

Soil cover	NDVI	Pixel quantity	Area (ha)	Area (%)
Exposed soil/Bodies of water	0.0 - 0.1	96	8.64	0.1366
Degraded pasture	0.1 - 0.2	946	89.01	1.4069
Pasture and tree vegetation	0.2 - 0.3	12,845	1156.32	18.2772
	0.3 - 0.4	26,810	2413.62	38.1505
Sparse healthy vegetation (including agriculture)	0.4 - 0.5	20,759	1868.31	29.5311
Dense healthy vegetation	0.5 - 06	8,780	790.29	12.4916

Source: Authors (2020).

In 2010, that is, after a decade of utilization of the healthy dense vegetation (Table 2), the area with preserved vegetation amounted to 12.49% of the total area. In relation to May 2000, there was a 1.76% decrease in the area of 111.6 hectares less than the preserved vegetation area. In relation to 2020 and 2000, the decrease in the area with preserved healthy vegetation was a 13.25% decrease, comprising an area of preserved vegetation less than 837.62 hectares, constituting a considerable loss of preserved vegetation area. This change is

closely related to anthropic activity, through logging for the construction of fences, grazing for animals, among other related activities.

Table 3 - Percentage of plant cover, average NDVI year 2020.

Soil cover	NDVI	Pixel quantity	Area (ha)	Area (%)
Exposed soil/Bodies of water	0.0 - 0.1	881	79.29	1.2533
Degraded pasture	0.1 - 0.2	799	71.91	1.1366
Pasture and tree vegetation (including agriculture)	0.2 - 0.3	23,099	2078.91	32.8599
	0.3 - 0.4	40,668	3660.12	57.8531
Sparse healthy vegetation	0.4 - 0.5	4,102	369.18	5.8354
Dense healthy vegetation	0.5 - 0.6	703	63.27	1.0001

Source: Authors (2020).

Whereas regarding the exposed soil, in the year 2000 (May), Caracol settlement had an area of 0.29% of exposed soil or degraded areas, in 2010 this percentage was 0.13%. Interestingly, there was a slight decrease in the amount of exposed soil, this was probably due to agricultural activity. From 2000 to 2010, the exposed soil area decreased approximately 0.16 ha, a non-significant decrease, however, not expected, since agricultural activity tends to degrade the soil. Between 2010 and 2020 there was a 1.12% increase in relation to the total area of the settlement, which means an area of 70.65 hectares.

4. Conclusions

It is possible to realize during the development of the present research that, significant changes in vegetation occurred due to the post-created occupation and approval of Caracol settlement directed by INCRA on August 11th, 1998.

The results showed that the preserved forest area had a continuous decline, reducing from 900 hectares in 2000 to 63.27 hectares in 2020. In the years studied, the native plant formation was also affected, which indicates that there was a reduction in vegetation and an increase in agricultural areas due to the occupation of family farming families.

The values of Normalized Difference Vegetation Index (NDVI), according to the classification shown in Tables 1, 2 and 3, highlighted that there was an increase in the area of exposed or degraded soil, and in 2000 it was 18.72 ha, in 2020, these exposed soil areas already registered 72.29 ha, that is, in relation to the total area, there was a 51.08% increase. It is considered that this change in the soil physical structure in vegetative terms and in the soil

use and cover is closely associated with human activity, more specifically activities linked to family agriculture. Finally, it was concluded that the Caracol settlement areas, especially the settlement areas, were partially deforested for the pastures and crops cultivations.

It is worth pointing out that the problem contained in this research still lacks further investigation, aiming to study this topic in more detail in order to contribute more effectively with the academic community and society. Therefore, it would be interesting for future works, the coverage of the temporal series of data for a better understanding of the phenomenon of environmental degradation and that of reforestation, using for that data of vegetation of satellite origin with greater temporal resolution, since it is a relatively small area, therefore, the greater the resolution, the more detailed the results will be presented.

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