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Geographic information systems in the delimitation of permanent preservation areas and vegetation index on the Jequitinhonha Valley municipality

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Abstract

Ecological restoration is a very important issue in view of the growing concern with issues related to the biodiversity. Brazil has a specific legislation for environmental issues, the Forest Code, which provides the definitions about permanent preservation areas (PPAs), especially the riparian forests and spring areas. The objective of this research was to determine PPAs of the Capelinha municipally hydrographic network and to perform the analysis of vegetal coverage through the Normalized Difference Vegetation Index (NDVI) based on brazilian Forest Code, in order to subsidize the identification of areas for ecological restoration. Geographic Information System tools were used to correct the demarcation of areas according to the prevailing legislation, with an extension covering all streams, flows, and rivers from one margin to the other, establishing the size of the permanent preservation areas, including springs. From the total area of 96.650 ha an area of ca. 7.839 ha (8.11%) was accounted for triparian and spring PPAs that should be preserved in compliance with current legislation. Through the NDVI map, it was possible to observe that many of these areas have some type of vegetation cover, but that these are not necessarily native, as required by legislation. This revealed the need for incentive projects to recover these areas, in addition to a more rigorous inspection, showing the efficiency of remote sensing techniques to this finality.
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Keywords: riparian forest, Brazilian Forest Code, NDVI

INTRODUCTION

Biodiversity conservation represents one of the greatest challenges in Brazil, as there has been a disorderly occupation since colonial times in native forests across the country, especially near streams and rivers, suppressing vegetation called riparian forests. These processes have caused great damage to local biodiversity, soil depletion, silting of watercourses, extinction of numerous fauna and flora, and reduced the quality of its water, much due to the disregard of the industry and inadequate disposal (SANTOS et al., 2017). According to Santos et al. (2017), riparian forests comprise a type of vegetation found on the banks of watercourses. They usually have peculiar characteristics such as tolerance to periodic flooding, and are able to adapt to sloping terrain. Given the accelerated rate of degradation in this forest formation due to its proximity to river courses, it was necessary to name them protected areas, especially in rural areas.

The absence of vegetation in riparian areas, near streams and rivers, reaches several biomes, such as in the Atlantic Forest, where a large part of forest remnants, especially in anthropic landscapes, are arranged as fragments, with high levels of disturbance, isolated, little known, or protected. This facilitates erosion processes that often start locally, but can affect very large areas, since eroded sediments are carried to watercourses in their various hierarchical orders, causing them to be silted.

To assist the public administration in making decisions that involve environmental issues, especially aimed at the protection of riparian forests, numerous mechanisms can be used. One of these is territorial management, which can direct or even discipline human actions. Among these, remote sensing techniques represent an important tool in the recognition of protected areas and in proper decision-making.

Currently, environmental preservation and restoration has been highlighted, and it is important to associate it with techniques that may enhance technical work development in a given area. In the specific case of Brazil, the new Forest Code, Law N°. 12.727 (BRAZIL, 2012) is the current legalization for the protection of permanent preservation areas (PPAs). This study aims to demonstrate the application of Geographic Information Systems (GIS) tools in the delimitation PPAs in rivers and spring surroundings for a case study of conservation status of vegetation using remote sensing techniques in the municipality of Capelinha, Minas Gerais, Brazil.

In this sense, the objective of this research was to determine the ciliary APPs of the Capelinha hydrographic network and to perform the analysis of vegetal coverage through the Normalized Difference Vegetation Index (NDVI) based on the current brazilian Forest Code, in order to subsidize the identification of areas for ecological restoration.

MATERIAL AND METHODS

2.1. Study area

The municipality of Capelinha is located in the mesoregion of the Jequitinhonha Valley, northeast of the Minas Gerais state, Brazil (Figure 1). Its municipality is located in the geographical coordinates 17,69º S of latitude, 42,52º W of longitude with 96.650 ha of total area (PNUD, 2000). The municipal see is at 948.0 m altitude, 427 km from Belo Horizonte, the state capital.

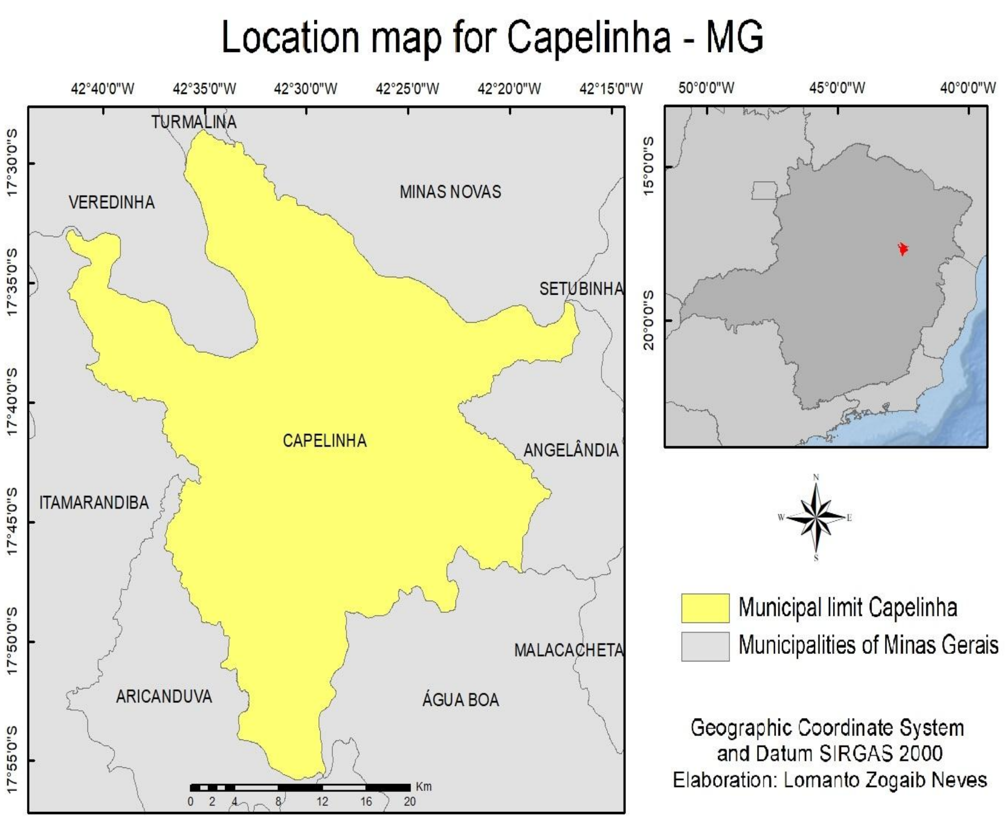

Fig.1: Location of the municipality of Capelinha, Minas Gerais state. Source: Own elaboration, based on IBGE data (2015).

The climate is classified as Cwa[1], according to the Köppen classification, with a dry period from April to September, and a rainy season from October to March (SÁ JÚNIOR, 2009). The average annual temperature is 25º C, and the average rainfall is 1,300 mm per year. According to the IBGE census (2010), its population is estimated in 34,803 thousand inhabitants, 70% of them living in urban areas. The productivity of the rural zone stands out for its agriculture. There are livestock like cattle herds, mainly milking cows, pigs, goats, horses, mules, and other birds. Eucalyptus silviculture is quite significant in the municipality.
As for hydrography, the municipality is located in the Araçuaí river basin (Figure 2) at the state level, and the federal basins division, in the Valley of Jequitinhonha, in Alto Jequitinhonha territory.

[1] Subtropical-dry winter.

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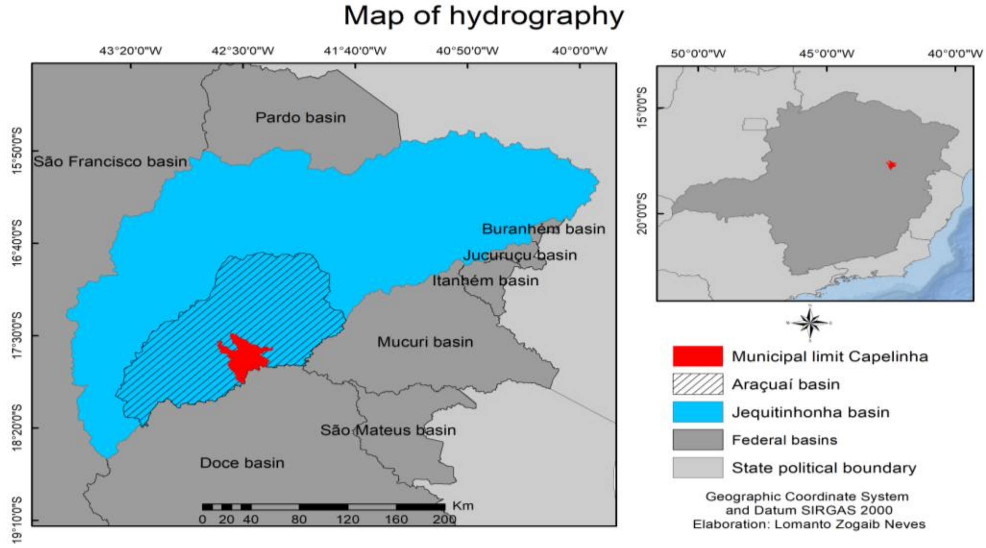

Fig. 2: Capelinha’s location within the state (a) and federal (b) watershed divisions. Source: Own elaboration, based on IBGE data (2015).

The municipality has several streams, rivers and brooks, mainly dendritic, and some rectangular and parallel (CRPM, 2004). There is sufficient water surface available, with the Itamarandiba and Fanado, the Sena and Francisco as main rivers, and the Areão and Fanadinho streams (Figure 3).

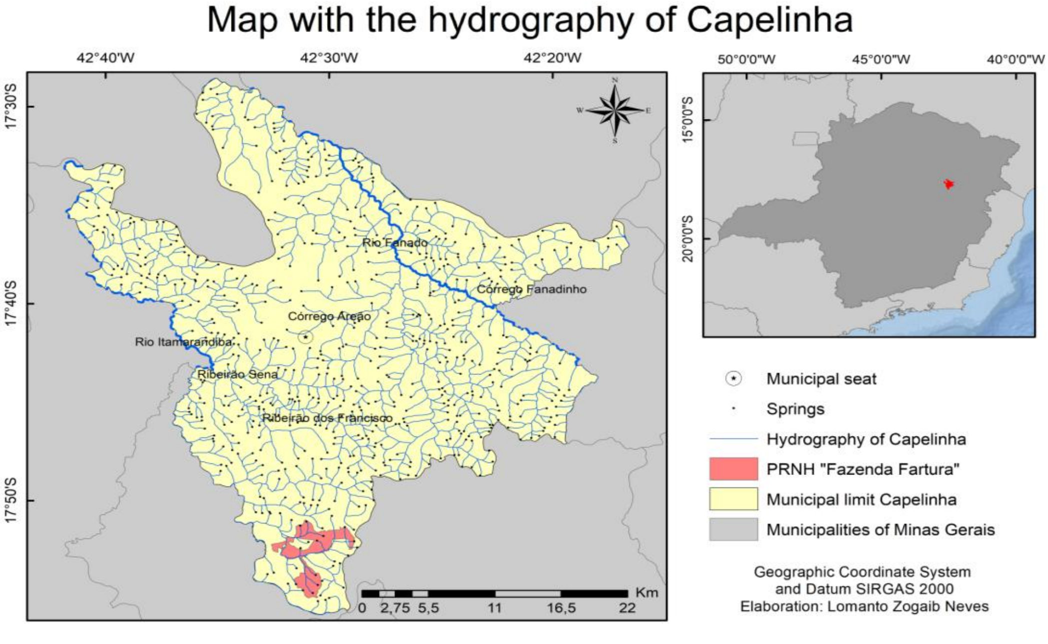

Fig 3: Map with the hydrography of the Capelinha municipality, with main watercourses and springs. Source: Own elaboration, based on IBGE data (2015).

Concerning vegetation, the municipality is located in a transitional area between the Cerrado and Atlantic Forest biomes (IBGE, 2010). Its vegetation is typical of the two biomes, varying according to relief and soil type. Phytophysiognomies such as campo cerrado, cerrado, deciduous seasonal montane forest, and semidecidual seasonal forest are found as vegetation cover. The municipality has a Private Natural Heritage Reserve (PRNH), "Fazenda Fartura", with a total area of 1,477.86 hectares (Figure 3) destined to the conservation of biodiversity with predominance of the Phytophysiognomy of the Semideciduous Seasonal Forest (BIOPRESERVAÇÃO, 2009). It is owned by CEMIG Geração e Transmissão S/A, regulated by the 1998 Decree No. 39.401 of the State Government of Minas Gerais. It was created by requirements in the Environmental Licensing process of the Irapé Hydroelectric Power Plant, located on the Jequitinhonha River, in the municipality of Grão Mogol, operative since 2006.

2.2. PPAs delimitation

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In the GIS environment, PPAs were delineated for all watercourses and springs in the Capelinha municipality using the database provided by IBGE, in the ArcGIS®10.3 program.
Using the "Measure" tool, watercourses were measured at their banks, and the values obtained were stored in attribute tables in the environment. The same course was measured, in some cases, in several sections, considering that the distance between the banks did not remain the same, which could influence the size of the riparian PPAs.
A new attribute table was created from bank averages of the delimited watercourses containing information regarding the size of the marginal areas of the PPAs for each border in accordance with the Forest Code (article 4, Law 12.727/12).
An attribute table for watercourse surroundings was created delimiting 50 m of surrounding areas for protection based on the same legislation.
Using the "Buffer" tool, available in the "Geoprocessing" tab, the PPA areas for the water and spring courses were delimited. For each margin distance, two processing operations were performed: one for the left margin and another for the right margin. This procedure is standard in this type of analysis, since the same course can have distance of distinct banks, or only one of the banks could be within the municipality.
In some situations, the PPAs of spring and riparian occupied the same area, so the generated polygons were united. This was done so that the same area was not counted twice as preserved.

2.3. Determining the PPAs' Normalized Difference Vegetation Index (NDVI)

Once PPAs were delimited, the region was processed using images from the Rapideye satellite sensor in 2015, acquired in the image catalog of the Ministry of the Environment (MMA), available at http://geocatalogo.mma.gov.br/. This site allows access only to registered users and public institution employees.
Rapideye images are orthorectified when provided, that is, corrected for relief displacements. Thus, in this study, the atmospheric correction of the images was performed based on the radioactive transfer model (CARVALHO; BAPTISTA, 2012).
The NDVI was developed with the purpose of highlighting the spectral behavior of the vegetation in relation to the soil and other land surface targets, facilitating the monitoring of preserved areas, as well as the efficiency of areas recovery techniques degraded (MOREIRA, 2012). The NDVI is calculated from the following equation:

$$NDVI = \frac{IPV-V}{IPV+V} \qquad \text{(Equation 1)}$$

Where: IPV = near infrared band; V = red band.
IPV and V correspond to bands 5 and 3 respectively in Rapideye images. The values obtained with the NDVI are contained in the same scale of values, between -1 and 1, where the former is associated with areas of low reflectance, that is, low vegetation density, while the latter has high reflectance or very dense vegetation (CARVALHO JUNIOR et al., 2008; GAMARRA et al., 2016). The maps generated have three colors in different shades, which indicate the degree of canopy cover of the analyzed area. The colors are blue, for denser coverings, yellow for intermediate coverings, and red for low cover or absence of cover. Statistical analyzes of the data obtained in ArcGIS were performed in Excel® data software

RESULTS

PPAs for all watercourses and springs are presented in Figure 4. Out of the total 96.650 ha of the Capelinha municipality, 7,839.81 ha of PPA were recorded for watercourse banks and springs' surrounding areas, that is, 8.11% of the total area of the municipality. 502.12 ha from the total PPA calculated, or 0.52% of the municipal area, destined to PPA in the surroundings of springs according to the current brazilian Forest Code, considering 50 m radius (BRAZIL, 2012).

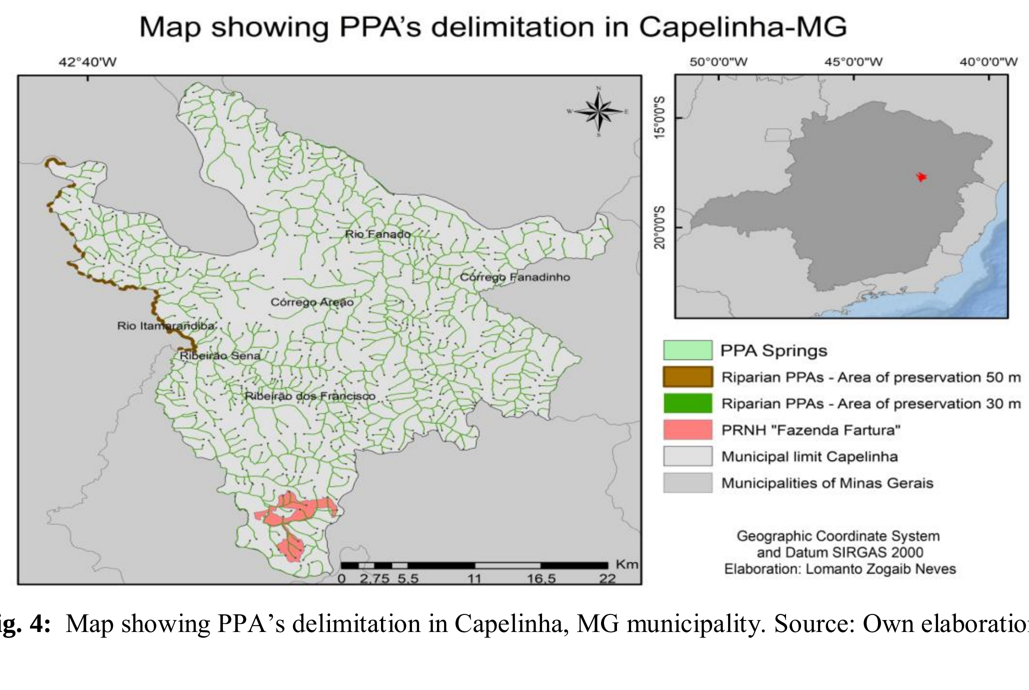

Fig. 4: Map showing PPA's delimitation in Capelinha, MG municipality. Source: Own elaboration.

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Riparian PPAs account for a total of 7,337.69 ha or 7.59% of the total municipal area. 192,682 ha are destined for the banks of the Itamarandiba River, located west of Capelinha (Figure 4), in a border area with municipalities of Aricanduva and Itamarandiba which, in some stretches, is drained by the municipal area.

The Itamarandiba river has banks that vary within the second category indicated by the current Forest Code, greater than 10 and less than 50 m (BRAZIL, 2012). Therefore, its PPA for riparian forests should be 50 m for each margin.
The other watercourses measured fall within a 10 m margin, including the Fanado River (north-north center of the municipality, Figure 4). According to the current legislation, the environment's area of preservation should be 30 m for each margin, which totals 7,145,015 ha of protection areas for the municipality's riparian forests.
In Fazenda Fartura, eleven springs were mapped in an internal area, or bordering the PRNH, in addition to watercourses that drain it, with a width of less than 10 m (Figure 5). In this sense, riparian PPAs must have a protection range of 30 m for each margin.

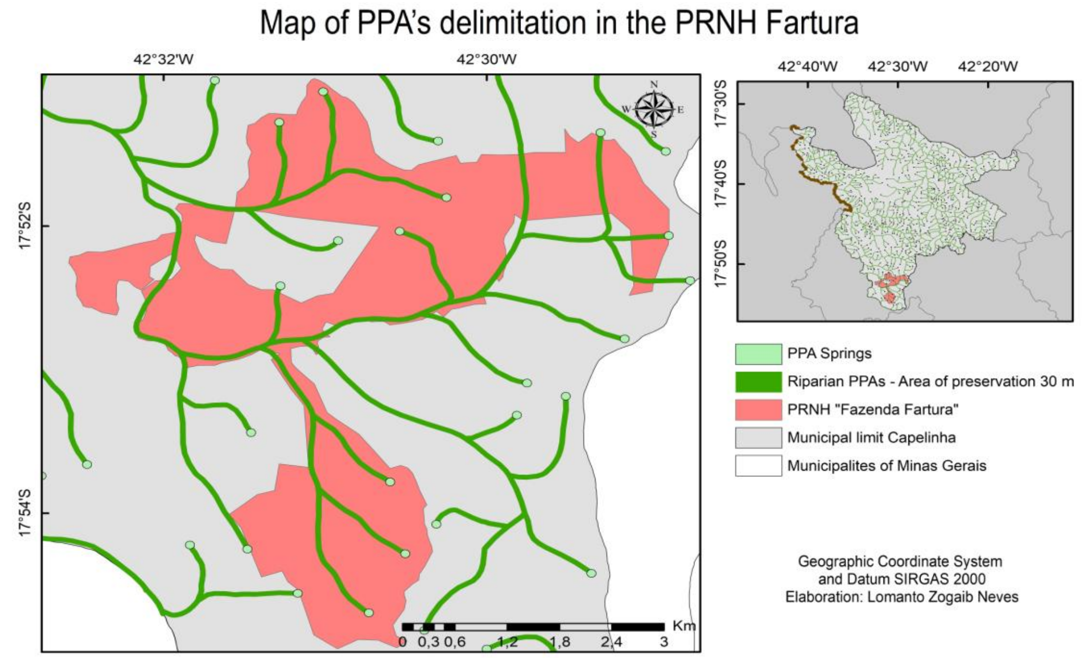

Fig. 5: Map showing PPA's delimitation that curtail PRNH Fartura. Source: Own elaboration.

DISCUSSION

Regarding the NDVI index for the year 2015, most PPAs have yellowish shades with values between 0.20321 and 0.0213 on 30 m banks, and 0.1562 at 0, 0021 on 50 m banks (Figure 6). The indices indicate that there is some vegetation cover, but no canopy density. Generally, there are both Cerrado Biome (center-north) and the Atlantic Forest Biome (south and southeast) vegetation in the municipality, which can influence the indexes found. NDVI time series on different types of land cover in work Trentin et al. (2013) found values close to 0.3, indicative of vegetation coverage of Cerrado, agricultural, and pasture areas.

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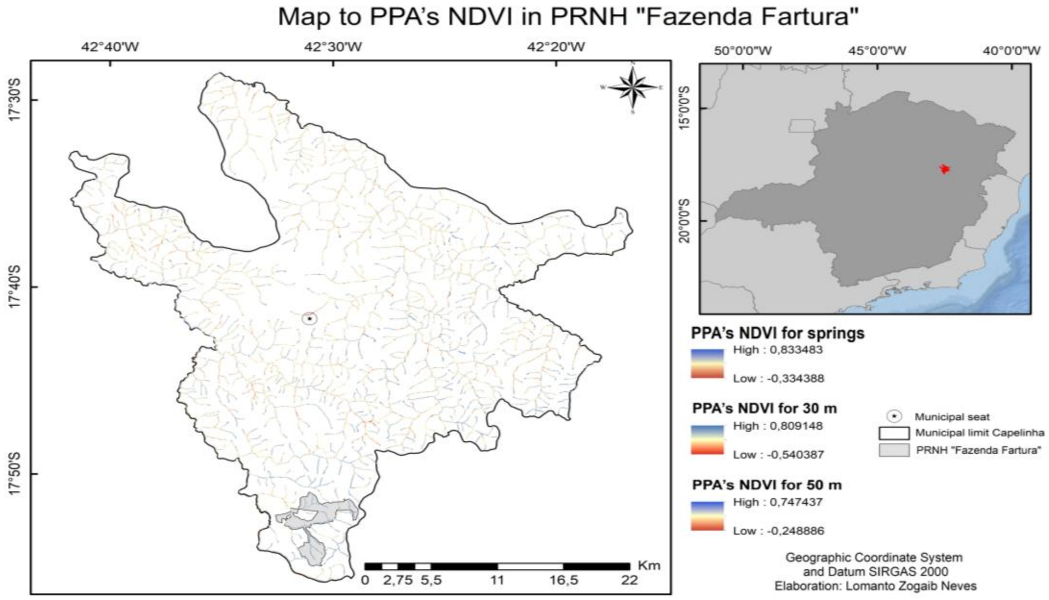

Fig. 6: PPA's NDVI in PRNH Fartura. Source: Own elaboration.

In the case of Capelinha, it is important to emphasize that abundant coverage is compliant with legislation. However, land uses that are very common in the region, such as agricultural crops, pasture, and forestry, cannot be considered as positive in terms of biodiversity conservation. This was also shown in Rodrigues and Rodrigues (2012), which studied the city of Botucatu, São Paulo state, Brazil, found low NDVI in most of the municipality, including marginal regions that were related to the region's agricultural expansion.

Figure 7 shows some fragments in red tonality, especially in the central and northwest region of the municipality. This means absence of coverage (index values between -0.01 and -0.540387 for riparian PPA of 30 m, and -0.012 to -0.288886 for riparian PPA of 50 m). In some cases, the absence of forest cover is related to rocky outcrops, especially in the northwest. However, in most situations, it can indicate places where there is no vegetation cover, or some exotic, which, in addition maintaining biodiversity, may have problems related to soil erosion, and consequent sedation of the watercourses. Reis et al. (2009), who evaluated PPPs in the municipality of Bandeirantes, Paraná state, Brazil, verified that a large area where there should be native vegetation was either uncovered or inadequately covered by pastures or buildings.

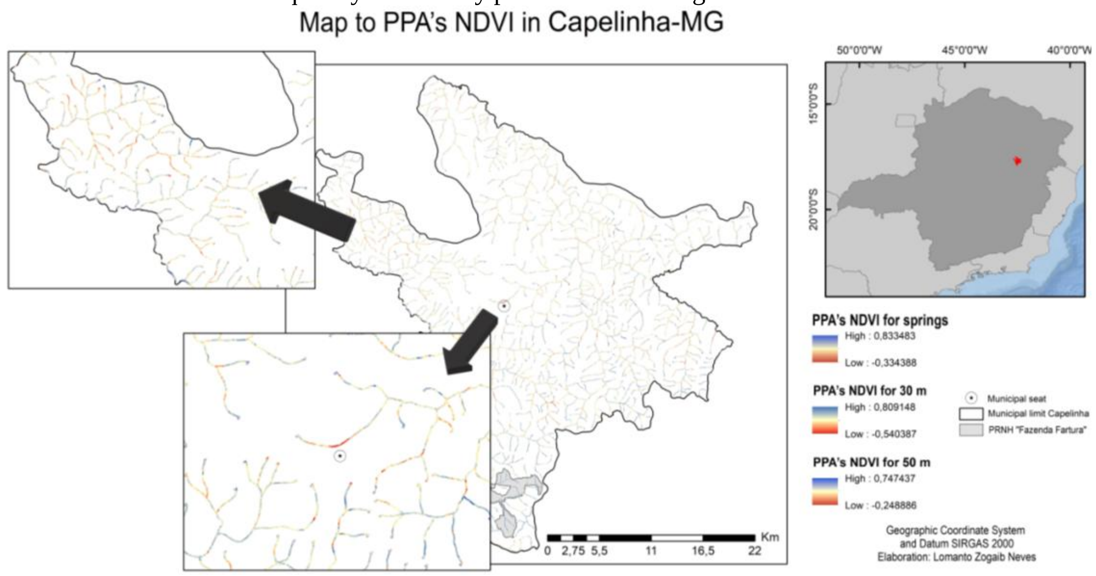

Fig. 7: Highlight in the NDVI map for the PPAs in the municipality of Capelinha, MG, in the upper part of the northwest region, in the lower area of the urban region of the municipality. Source: Own elaboration.

Figure 8 depicts the vegetation situation in the PRNH Fazenda Fartura and its borderlands. Tone predominance within the reserve area indicates dense vegetation cover, which is indicated for vegetation in area for the region's biome. This does not occur in surrounding properties, where intense exploration of areas that, by the law, should be preserved was evident during fieldwork.

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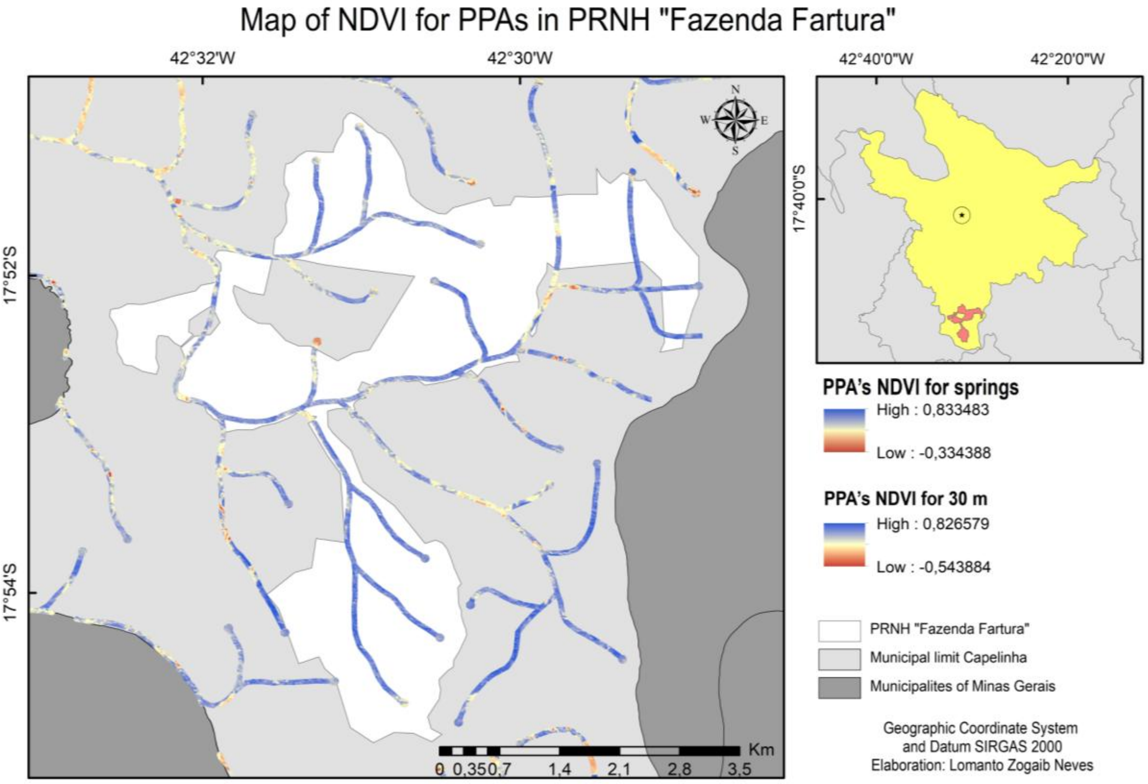

Fig. 8: Highlight on NDVI map for PPAs in PRNH Fartura and its bordering. Source: Own elaboration.

The municipal see of Capelinha, also characterized by red tonality, is drained by the Areão stream, which has low NDVIs (-0.23454) in its banks, indicative of inappropriate use and occupation of the land in urban area, besides the rural zone. A similar situation was found by Rodrigues and Rodrigues (2012) who, using the NDVI to evaluate Botucatu's vegetation cover, found 0.1 NDVI for the urban area close to those agriculturally developed within the municipality.

Comparing Figures 7 and 8, it is possible to state the importance of the PRNH for the region, since shades indicating low vegetation cover predominate in areas where there is no reserve, either in the urban center or in rural areas, a fact corroborated by fieldwork.

The use of the NDVI as a tool for ecological restoration has already been classified as positive in Vila Nova et al. (2013) study, which sought to monitor the area of mangroves on the coast of Pernambuco state, Brazil. The authors pointed out that this index allows following structural modifications, which reveal relevant aspects regarding land occupation, as a substitution of native vegetation formations for urbanization. Furthermore, it was possible to map areas in the process of restoration that required differentiated measures for the maintenance of its ecosystem.

The PRNH Fazenda Fartura Environmental Zoning Map developed during the preparation of the management plan of the conservation unit (Figure 9) is presented. It shows the PRNH territory subdivided into the Wild Zone comprising 1365.3 ha, Visitation Zone with 23.6 ha, and Environmental Recovery Zone with 88.9 ha (BIOPRESERVAÇAO, 2009).

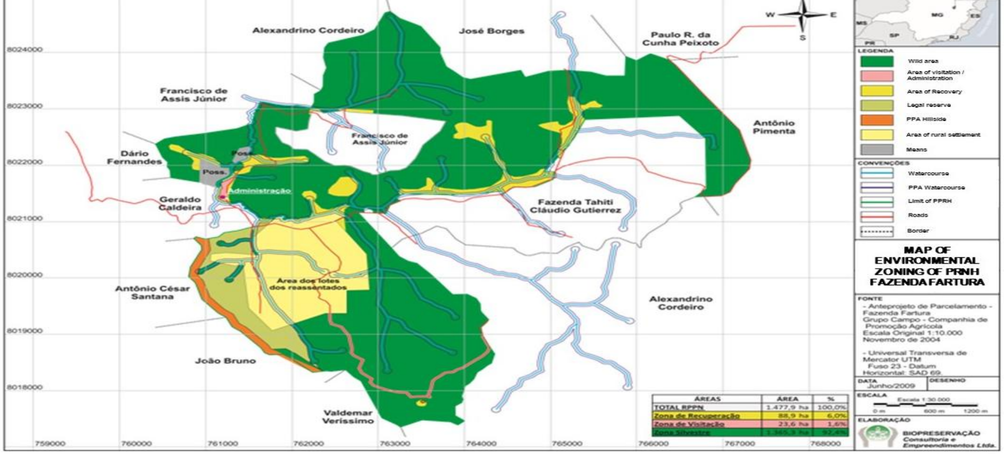

Fig. 9: Map of Environmental Zoning of PRNH Fazenda Fartura with detailing of owners in its bordering areas. Source: Modified from the Management Plan of the Conservation Unit (CEMIG, 2018).

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The importance of preserving riparian and spring areas is not even identified in the adjacent properties of the reserve. This is clear when comparing the shades of PPA areas within PRNH with the property of Francisco de Assis Junior (Figure 8). Riparian PPA shows yellow tones, which indicates less dense canopy cover. This is not the case when riparian PPA is within PRNH limits, where the tones tend to be more bluish, implying greater vegetation cover.

The GIS tools was also to analyze the conflict of land use with PPAs in the work developed by Nardini et al (2015), where through the use of geoprocessing it was possible to identify areas of conflict of interest and to elaborate digital maps, which will facilitate future process of recovery of environmental areas and also, when necessary, the application of sanctions, according to the current legislation determines, by improper use of areas that should be preserved.

Another case of absence of ideal cover occurs to the southeast in Figure 8, where, in the same property, riparian PPA of different streams no longer have higher NDVIs, indicating greater coverage, for intermediate values. This is directly related to the terrain's slope decrease, which facilitates the exploration of the area for agricultural purposes. This situation, according to current legislation, is not incorrect, since it has been proven that PPA exploration initiated before 2008 and can be continued depending on the module size of the property.

The lowest NDVIs observed for Fazenda Fartura and adjacent areas (Figure 8) are located northeast of the PRNH, in private rural property in PPA of spring environment of one of the streams that, although not drained by the reserve, is in the damping zone. This is a very worrying situation, because usually producers themselves protect the spring areas, as they are held responsible for a property's water supply. Land use in a spring area can degrade the water table, damaging water flow in the region, and increasing several environmental problems.

Some of the demarcated PPA, both riparian and springs of areas bordering the PRNH, do not have any protection and, sometimes, there are agricultural and forestry activities in areas that should be protected. Mascarenhas et al. (2009) report a similar situation in their analysis of the remaining vegetation cover in the Araguaia river basin, using NDVI. The authors found that more than 60% of the vegetation in the riverbanks was not native, replaced by agricultural crops.

Although it is important to protect these regions, when a PPA is not within the PRNH limits, the green coloration decreases, sometimes in spring areas, and brown tones are frequent. This indicates less vegetation cover than necessary for their protection. The condition of the PRNH studied is very different from that used as in Lobato et al.'s (2010) study carried out in Cabo Frio, RJ, where low NDVIs were found within the PRNH. This indicates that this area was being used for purposes other than preservation, with the aggravating circumstance that the region had endangered species. According to the authors, this was due to the exploitation of the area for urban use and mineral extraction.

The use of NDVI to assess land cover was highlighted in Furlan, Filipini and Reis (2016), who verified through NDVI the influence of land use and land cover on water quality parameters. In the paper, the authors pointed out that, with the use of the vegetation index, it was possible to identify areas where there was an explicit decrease of the native areas, replaced by agricultural crops.

CONCLUSIONS

GIS tools were efficient to delimit PPAs within a certain environment, in this case, a municipality. Vegetation analysis techniques with NDVI were also able to show clear distinctions, proving efficient as well.

The municipality of Capelinha, Minas Gerais, has its waterway network almost entirely in the lower protection range of riparian PPA, as established in the new forest code. Although they are relatively small conservation areas, when compared to other protection areas decreed by law, NDVIs indicate that many watercourse banks are without vegetation cover or land use cover, such as pastures, or crops agricultural activities.

Discrepancy between the vegetation covers of the municipality's PPAs and PRNH "Fazenda Fartura" was evidenced, which demonstrates the importance of this type of reserve for environmental preservation, and maintaining spring quality.

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