ENVIRONMENTAL ASSESSMENT OF RIPARIAN FORESTS IN THE ALTO MEIA PONTE WATERSHED – GO, BRAZIL

DIAGNÓSTICO DAS MATAS CILIARES DA BACIA HIDROGRÁFICA DO ALTO MEIA PONTE - GO

DIAGNÓSTICO AMBIENTAL DE LAS FORMACIONES DE BOSQUE DE GALERÍA EN LA CUENCA HIDROGRÁFICA DEL ALTO MEIA PONTE – GO

https://doi.org/10.56238/sevened2026.008-072

Pedro Luiz Teodoro Clemente de Oliveira[1], Nori Paulo Griebeler[2], João Ricardo Nobre Ramos[3]

ABSTRACT
Monitoring vegetation degradation in the surroundings of water sources is essential to assess environmental impacts and to support actions aimed at restoring ecological balance between riparian forests and watercourses. In this context, the proposed study is justified by integrating geoprocessing and remote sensing tools into environmental analysis. This study aimed to evaluate the presence and condition of remnant vegetation within the Permanent Preservation Areas (PPAs) of the Meia Ponte River Basin upstream of the Raw Water Pumping Station operated by SANEAGO in Goiânia, Goiás. The assessment procedures involved the use of QuantumGIS (QGIS) software to delineate the watershed based on the Digital Elevation Model (DEM) from the TOPODATA project. Publicly available satellite imagery from Landsat 8–9 and Sentinel-2 was also used, along with the application of the Normalized Difference Vegetation Index (NDVI) and pixel reclassification to identify Cerrado phytophysiognomies that include riparian vegetation. The results revealed differences in sensor accuracy, with Sentinel-2 presenting higher spatial accuracy. They also indicated that only 3.62% and 5.09% of the total basin area (Landsat 8–9 and Sentinel-2, respectively) corresponds to remnant vegetation within PPAs, highlighting significant pressure on riparian forests associated with water sources. The study demonstrated the relevance of geotechnologies as effective tools for assessing PPAs in the watershed under analysis. Satellite image analysis enabled accurate mapping of river tributaries and identification of the presence and absence of vegetation adjacent to water sources within legally protected buffer zones.

Keywords: Remnant Vegetation. Vegetation Index (NDVI). Native Vegetation Conservation. Landsat 8-9. Sentinel-2.

[1] Undegraduated student in Agronomy. Escola de Agronomia. Universidade Federal de Goiás (UFG).
E-mail: pedroluizteodoro25@gmail.com
[2] Dr. in Agricultural Engineering. Escola de Agronomia. Universidade Federal de Goiás (UFG).
E-mail: nori@ufg.br
[3] Undegraduated student in Agronomy. Escola de Agronomia. Universidade Federal de Goiás (UFG).
E-mail: nori@ufg.br

RESUMO
O monitoramento da degradação da vegetação no entorno de mananciais é fundamental para avaliar impactos ambientais e subsidiar ações voltadas ao restabelecimento do equilíbrio ecológico entre a mata ciliar e os cursos hídricos. Nesse contexto, a proposta se justifica ao integrar ferramentas de geoprocessamento e sensoriamento remoto à análise ambiental. O presente trabalho teve como objetivo avaliar a presença e a situação da vegetação remanescente nas Áreas De Preservação Permanente (APPs) da Bacia Hidrográfica do Rio Meia Ponte a montante da Estação Elevatória de Água Bruta da SANEAGO em Goiânia (GO). Os procedimentos de avaliação envolveram o manuseio do software SIG QuantumGIS para delimitação da bacia hidrográfica através do MDE do projeto TOPODATA, utilizando também como base imagens dos satélites Landsat 8-9 e Sentinel-2 adquiridos por bancos de dados públicos, aplicação do índice NDVI e reclassificação dos pixels para identificação da fitofisionomia do Cerrado que contemplasse as matas ciliares. Os resultados demonstraram diferença na acurácia dos sensores, sendo o Sentinel-2 com maior acurácia espacial, e indicaram que apenas 3,62% e 5,09% (Landsat 8-9 e Sentinel-2 respectivamente) da área total da bacia corresponde a vegetação remanescente em APPs, evidenciando significativa pressão sobre as matas ciliares dos mananciais. O presente trabalho demonstrou a relevância do uso de geotecnologias, como ferramentas eficazes para a avaliação de APPs na bacia hidrográfica em questão. A análise das imagens dos satélites permitiu mapear com precisão os afluentes do rio e identificar a presença e ausência de vegetação contígua aos mananciais, dentro das faixas legalmente protegidas.

Palavras-chave: Vegetação Remanescente. Índice de Vegetação (NDVI). Conservação da Vegetação Nativa. Landsat 8-9. Sentinel-2.

RESUMEN
O monitoramento da degradação da vegetação no entorno de mananciais é fundamental para avaliar impactos ambientais e subsidiar ações voltadas ao restabelecimento do equilíbrio ecológico entre a mata ciliar e os cursos hídricos. Nesse contexto, a proposta se justifica ao integrar ferramentas de geoprocessamento e sensoriamento remoto à análise ambiental. O presente trabalho teve como objetivo avaliar a presença e a situação da vegetação remanescente nas Áreas De Preservação Permanente (APPs) da Bacia Hidrográfica do Rio Meia Ponte a montante da Estação Elevatória de Água Bruta da SANEAGO em Goiânia (GO). Os procedimentos de avaliação envolveram o manuseio do software SIG QuantumGIS para delimitação da bacia hidrográfica através do MDE do projeto TOPODATA, utilizando também como base imagens dos satélites Landsat 8-9 e Sentinel-2 adquiridos por bancos de dados públicos, aplicação do índice NDVI e reclassificação dos pixels para identificação da fitofisionomia do Cerrado que contemplasse as matas ciliares. Os resultados demonstraram diferença na acurácia dos sensores, sendo o Sentinel-2 com maior acurácia espacial, e indicaram que apenas 3,62% e 5,09% (Landsat 8-9 e Sentinel-2 respectivamente) da área total da bacia corresponde a vegetação remanescente em APPs, evidenciando significativa pressão sobre as matas ciliares dos mananciais. O presente trabalho demonstrou a relevância do uso de geotecnologias, como ferramentas eficazes para a avaliação de APPs na bacia hidrográfica em questão. A análise das imagens dos satélites permitiu mapear com precisão os afluentes do rio e identificar a presença e ausência de vegetação contígua aos mananciais, dentro das faixas legalmente protegidas.

Palabras clave: Vegetación Remanente. Índice de Vegetación (NDVI). Conservación de la Vegetación Nativa. Landsat 8-9. Sentinel-2.

1 INTRODUCTION

The presence of native vegetation in the surroundings of the springs is essential for maintaining the ecological flow throughout the year because they reduce the natural loss of water along the entire spring, mainly through infiltration and evaporation, but also by reducing sedimentation and erosion, and interception of rainfall that allows a better effective infiltration of water into the soil (Ferraz *et al*., 2014 *apud* Ferreira *et al*., 2019).

By observing the behavior of water over a watershed cutout, it is possible to trace the different ways in which water loss, consumption or runoff occurs. The main elements that alter the availability of water through the natural or artificial withdrawal of natural watercourses are: evaporation, insolation, infiltration, human consumption (catchment), watering, irrigation (catchment), natural evapotranspiration of plants, among others; factors that are also considered in modeling studies of soil surface loss and water availability in land use scenarios (Lima; Ferreira; Ferreira, 2018)

In addition to the consumption itself, which would be the export of water from the springs, the natural recharge of the watersheds through rainfall and recharge zones must be considered. The water tables are supplied by precipitation that reaches regions of deep and permeable soils, in addition to being maintained by native vegetation that prevents the evaporation of water, maintains and redistributes rainwater (Hollanda *et al*., 2014). Riparian forest areas are considered and described, by Brazilian legislation, protected zones that play an important role in the ecosystem. As described by Law No. 12,651 of May 25, 2012:

> II – Permanent Preservation Area – APP: protected areas with the environmental function of preserving water resources, landscape, geological stability and biodiversity, facilitating the gene flow of fauna and flora, protecting the soil and ensuring the well-being of human populations. (Brazil, 2012, p. 2).

In many cases, vegetation is suppressed in Permanent Preservation Areas and, regardless of legality, compensation for the environmental damage caused is mandatory, which in turn is governed mainly by Law No. 12,651/2012 (nationwide), State Law No. 18,104/2013 and State Law No. 21,231/2022.

Thus, the recovery of the degraded area, especially in the vicinity of springs, is at the mercy of both the actions of the owner of the property where the suppression occurred and the environmental agencies responsible for inspection. Therefore, it is common to find areas along the springs where there is an invaded, degraded or absent Permanent Preservation Area. Studies on the adequacy of land use in PPAs highlight the need for restoration and inspection actions to ensure the water function of these areas (Santos *et al*., 2014)

In the study by Novaes (2022), significant degradation was identified in the APPs along the water courses and in the surroundings of springs within the Meia Ponte River Catchment Basin. The use of remote sensing and classification techniques has been pointed out as an effective tool for this monitoring and decision-making (Liu, 2006; Maxwell; Warner; Fang, 2018). The importance of monitoring native vegetation around water sources is reinforced as a method of understanding and evaluating the impacts of the loss or recomposition of fauna on the entire agroecosystem.

The entire territory of the state of Goiás is part of the Cerrado biome, a tropical savannah of high ecological importance due to its biodiversity and the distinct phytophysiognomies that compose it. The configuration of the landscape in the Cerrado is closely associated with geological formations, soil types and reliefs, factors that, together with the presence of springs and watercourses, shape local hydrological patterns. In addition, the Cerrado is recognized as Brazil's "water tank", housing springs that contribute to several large hydrographic regions of the country — a characteristic that reinforces its relevance for water security and for the conservation of riparian forests. (Brazil, 2023).

The springs in particular are the source of life for all the vegetation present, which in turn fulfills the fundamental function of protecting the soils around the springs, preserving the flow of the source and contributing to the quality of the water. In search of the need to mitigate environmental impacts, different laws emerged that established legal instruments such as Permanent Preservation Areas (APPs) and Legal Reserves (RL) that delimited mandatory areas on the property that must be preserved and recomposed. However, the effectiveness of the legislation is dependent on the pressure of inspection by the competent environmental agencies and on the non-compliance with the regulations on rural properties.

The way environmental agencies assess the presence of illegal plant suppression is through geotechnology tools, in particular, the temporal analysis of satellite images. The presence or absence of native vegetation is monitored, whether it is surplus vegetation on a property or conservation areas such as APP or RL and through this, the environmental agency plans together with the owner, the recovery of irregularly suppressed areas.

The temporal analysis of satellite images is essential for the monitoring of riparian forests along water courses. The first step to investigate the environmental impacts on the springs through the degradation of native vegetation is the correlation between the native vegetation and the ecological flow of the spring. With the integrated analysis between land use, remaining native vegetation and water availability, the entrepreneur and the environmental agency can jointly contribute to a more sustainable management of natural resources, reconciled with existing public policies.

Naturally, the hydrological flow of the river is impaired throughout the year, especially in seasons of prolonged drought, due to the absence of riparian forest. With these functions compromised, the trends are erosive processes caused by the water course itself, complete drying of the source and loss of biodiversity. From a legal point of view, the Brazilian Forest Code (Law No. 12,651/2012) clearly establishes the principle that natural resources, especially water, native vegetation and soil, are goods of common interest to the whole society.

Thus, the monitoring of the degradation of vegetation around water sources is important in terms of evaluating the impacts and developing potential solutions to reestablish the ecological balance of the relationship between riparian forest and water course, but also to generate economic return for those who have water sources on their properties through the various benefits that good management of water resources brings.

The proposal is also part of an academic effort to integrate geoprocessing and remote sensing tools in environmental analysis, understanding the relationship between land use and water availability, assessing impacts, bringing results that support public policies and providing strategies for integrated landscape management through agroecological practices that reconcile agricultural production and conservation of water resources. In this context, the proposal is justified by integrating geoprocessing and remote sensing tools to environmental analysis.

The objective of this research is to evaluate the presence of native vegetation in the Permanent Preservation Areas through the classification of satellite images (using Landsat and Sentinel-2) considering the agroecosystem of the Meia Ponte River Basin upstream of the Meia Ponte Raw Water Pumping Station in Goiânia, Goiás. The specific objectives are: to delimit the study area and identify the tributaries of the watershed from Digital Elevation Models and public cartographic bases; process and analyze images from the Landsat and Sentinel-2 satellites to map the vegetation in the APP zone, comparing their precision, accuracy and performance; develop and test a reproducible methodology using exclusively free software and public data for vegetation identification in PPAs; and to discuss the implications of the results for the formulation of public policies aimed at the conservation of native vegetation and the sustainable management of water resources.

2 THEORETICAL FRAMEWORK

Once a certain point in the stretch of a spring is chosen, there is an imaginary layout that delimits a drainage area, a region of the earth's surface that receives rainwater, sediments and dissolved materials for a common outlet, a focal point (Santana, 2003). By delimiting a route between these focal points, a fluvial channel is formed.

> [...] The term river basin refers to a natural geographical compartmentalization delimited by water dividers. This compartment is drained superficially by a main watercourse and its tributaries." (Santana, 2003, p. 27).

A system determined by biotic and abiotic factors has a volume of water input and an output volume, being determined by some factors such as evaporated, transpired and infiltrated water (Silva, 2014 apud Silveira, 1993). However, an important factor that interferes with the behavior of the basins is surface runoff.

When the earth's surface is saturated with water or impermeable, the water drains superficially towards a closer watercourse (Miranda; Silva; Oliveira, 2010). This phenomenon is important when observing the presence of vegetation to buffer, absorb and redistribute rainwater without harming and altering the physical properties of the soil.

When there is the presence of native vegetation, the behavior of water in relation to the earth's surface changes significantly, the presence of vegetation cover in the soil regulates factors such as erosion, sediment transport, rainfall interception and effective water infiltration by the soil profile (Carvalho, 2019).

The capacity to retain and recharge the volume of water flowing in the springs of a watershed is determined by the capacity of water generation by the springs in each spring, but also by the recharge areas. The infiltration areas, as the recharge areas are known, are zones that allow the infiltration of water into the soil profile, reaching the water table that supplies the water mines and the springs themselves (Santana, 2003).

The potential of a watershed greatly delimits an activity that depends on water in a given region. Human activity, in turn, also has a direct impact on the behavior of the basins, agricultural pressure, for example, is an anthropogenic interference that alters the landscape through the conversion of land use. Naturally, the absence of vegetation, soil compaction, and landscape degradation through erosion caused by poor soil management lead to direct consequences on the way water behaves in a basin.

Deforestation, therefore, is a lower-cost activity when compared to the leasing of new areas, in the Amazon, there is a direct correlation between deforestation and the expansion of cattle ranching and large-scale agriculture (Rivero, 2009). In the state of Goiás, mechanization of agropastoral activities has caused severe impacts on native vegetation, compromising important ecological functions of the agroecosystem, such as soil protection, recharge of watersheds, and the filtration of rainwater by the vegetation itself (Crestana; Reichardt; Silva, 1993; Campos *et al*., 2015).

Remote sensing and geoprocessing are essential elements in the dynamic and temporal monitoring of the landscape over time, allowing the identification of critical areas for conservation and restoration (Campos *et al*., 2015; Fitz, 2008). Therefore, to understand the impact of agriculture and livestock on native vegetation, especially riparian forests, a multidisciplinary analysis is needed quantifying changes in land use and vegetation cover, associating them with environmental and hydrological impacts.

In several rural properties in Goiás, APPs represent the only remaining native vegetation, making them vulnerable to agricultural pressure. In the context of the Meia Ponte River Basin, this soil conversion results in the degradation of riparian forests and loss of water retention of agroecosystems (Lima; Ferreira; Ferreira, 2018).

The monitoring of these activities serves as a regulatory framework both for the entrepreneur responsible for the intervention in nature, and for the inspection agency that seeks irregular interventions. Remote sensing plays an important role in assessing the condition of protected areas and facilitating this broadening of the focus from protected areas to entire landscapes (Wiens *et al*, 2009).

Currently, in Brazil, the main satellites used are Sentinel-2 and Landsat because they periodically capture images of the entire Brazilian territory and are made available for free on the internet. The diagnoses of the areas are made through the processing of satellite images in products such as maps and images that highlight different elements depending on the object of interest.

The use of GIS tools are crucial for monitoring the vegetation present in an area. According to Tagliari and Baptista (2020), the processing of satellite images through GIS tools allows the evaluation of the presence of APPs that have undergone intervention along several stretches, using vegetation indices as a criterion for evaluating the presence of vegetation.

The product varies according to the objective of each analysis, the study by Nepomuceno (2012) presents, as a reference, several maps prepared from the processing of images that best illustrate the reality of the Ribeirão Gomeral hydrographic basin, such as the vegetation cover and the contour lines. Geoprocessing, the area of knowledge responsible for this entire process, is described by Cubas and Taveira (2020) as being the means (through GIS) that it is possible to transform georeferenced data into information.

Orbital images are created from sensors attached to satellites that capture the radiation reflected or emitted by the Earth's surface. The characteristics of sensors change according to their purpose and technology and this directly influences the quality, accuracy and precision of the image. Sensors have different spatial, spectral and temporal resolutions, and should be considered according to the applicability of the image (Wiens *et al*., 2009).

The use of water by agriculture varies according to the type of production, availability of water granted in the springs and the need for the crop. In 2022, an assessment was made of the use of water by crops, both rainfed and irrigated, consuming a total of 9.2 thousand m³ per second, of which 864.8 m³ per second, that is, 9.4% of water supplemented via irrigation, the rest is characterized by rainwater and made available in the soil, without human interference (Ana, 2022).

The Landsat program has maintained an "uninterrupted multispectral record" of land surfaces since 1972, and Landsat 8, launched in 2013, reinforces this continuity by operating with an orbital lag of eight days compared to Landsat 7 (launched in 1999), increasing the frequency of revisits and the availability of images for environmental monitoring and surveys (Usgs, 2019).

The Copernicus Sentinel-2 mission has as its main objective is to monitor the variability in the Earth's surface conditions, supporting the monitoring of changes through a combination of wide bandwidth and high revisit frequency; the mission has a bandwidth of 290 km and offers 10-day revisits at the equator with one satellite and 5 days with two satellites, which translates into intervals of approximately 2–3 days at mid-latitudes (Copernicus, 2020).

3 METHODOLOGY

The research evaluated a portion of the Meia Ponte River Basin, upstream of the Meia Ponte Raw Water Pumping Station (EEAB) consisting of an area of approximately 1,662.15 km² that includes the municipalities of Goiânia, Goianira, Santo Antônio de Goiás, Brazabrantes, Nerópolis, Nova Veneza, Ouro Verde de Goiás, Damolândia, Inhumas and Itauçu.

This region carries a socioeconomic importance due to its strategic importance in urban supply, irrigation of agricultural systems and animal watering. The region, being within the state of Goiás, is also monitored by public agencies such as the State Secretariat for the Environment and Sustainable Development of Goiás (SEMAD-GO) which promotes different public policies and strategies for maintaining the watershed.

The mapping of the area was carried out using the free GIS tool QGIS, which performed the interpretation and analysis of the shapefile and raster files generated throughout the research. Through a Digital Elevation Model acquired through the TOPODATA project, only the area downstream of SANEAGO's Raw Water Pumping Station (EEAB) was cut, respecting the contour lines that converge to the point of interference (16°34'11.16"S 49°19'44.97"W).

To evaluate the vegetation in the APPs, satellite images obtained from the Landsat 8-9 Level 2 (Operational Land Imager - OLI) and Sentinel-2 (MultiSpectral Instrument - MSI) missions were used, which offer spatial resolutions of 30 meters and 10 meters, respectively.

Quantum GIS virtual environment was used to manipulate the data.

The delimitation took place through the Digital Elevation Model (MDE) file acquired through the TOPODATA project of the National Institute for Space Research (INPE). The quadrants in which the watershed area fits are 16s 51 ZN and 16s 495 ZN, the rasters files that provided the numerical altitude information (ZN extension) per pixel were specifically downloaded.

Due to the nature of the file, the Coordinate Reference System (SRC) was manually referenced from the original file, in this case, the SRC EPSG:4674 – SIRGAS 2000. The raster files were redesigned to be standardized according to the research reference system, SRC EPSG:31982 – SIRGAS 2000 (UTM Projection Zone 22S). The files were merged and cropped within the extension of the screen that contemplated the entire hydrographic basin upstream of the EEAB using as a reference the shapefile file made available free of charge by the SIGA-GO portal of SEMAD.

The extraction of the perimeter of the drainage area was carried out through three stages: delimitation of the basin, reclassification of the pixels of the raster image and polygonization of the reclassified pixels. The first and third steps were automated through Python scripts that, in addition to ensuring the execution of the procedure and generation of an error-free file, automated several steps that could have been done manually.

These scripts were generated and adapted with the help of Copilot, a Microsoft Artificial Intelligence assistant, for these scripts to be generated it is necessary to have an AI conduction methodology to acquire the desired result. The desired file is the "basin raster". The pixels in this file, due to the nature of their processing, generate pixels whose value ranges from 0 to 8000. These are representative values proportional to the pixel value of the file in which it was processed, with 0 being the northwesternmost pixel of the raster file and 8000 the southeasternmost pixel of the raster file, that is, respecting the natural slope of the terrain captured by the DEM. The "basin raster" file is reclassified using the native QGIS algorithm "Resort by table", using the values presented in Table 1 as a parameter.

Table 1

Pixel reclassification table

Minimum Value	Maximum Value	Pixel Value
5264	6836	1
- ∞	5263	0

Source: The authors, 2026.

The delimiter was defined according to the manual evaluation of the gray spots formed in the graphical representation of the raster file using a simple gray band. The pixel value at the EEAB point is 5264, so every basin is bounded by the pixels above this value and below 6836. The maximum limit was defined because, in every extension of the raster file, there are points of elevation greater than that of the watershed, so a maximum delimiter must be inserted in the algorithm to correct the formation of the perimeter of the drainage area. When reclassifying the raster file from the basin, this generates a new black and white raster file, where black is the representation of the pixels with an assigned value of 1 and white, are the pixels with an assigned value of 0.

To identify the vegetation present within the PPA boundaries, satellite images from Landsat 8-9 Level 2 and Sentinel-2 Level 2 were used. The rasters files were acquired through the official USGS and Copernicus EarthExplorer portals. For the analysis of the presence of vegetation, the use of the NDVI (Normalized Difference Vegetation Index) vegetation index was considered. The index uses in its calculation the digital numbers (ND) of the bands in the Near Infrared and Red range.

$$NDVI = \frac{ND_{Infravermelho\ Próximo} - ND_{Vermelho}}{ND_{Infravermelho\ Próximo} + ND_{Vermelho}} \quad (1)$$

The files have been redesigned for SRC EPSG:31982 – SIRGAS 2000 (UTM Projection Zone 22S). The rasters were cut using the overlay layer of the vector file of the drainage area, thus obtaining a raster file delimited by the watershed. To obtain the raster file calculated according to the NDVI index using the B4 band (spectral resolution of 0.76 – 0.90 μm) and the B5 band (spectral resolution of 1.55 – 1.75 μm) for Landsat 8-9, for Sentinel-2, the B4 band (spectral resolution of 0.665 μm) and the B8 band (spectral resolution of 0.842 μm) were used. The NDVI classification followed the classification of Bitencourt *et al.* (1997) for the phytophysiognomies of the Cerrado (Table 2).

Table 2

NDVI classes according to phytophysiognomy

Phytophysiognomies	Classes NDVI
Dirty Field	0.0261 to 0.2036
Wet Field	0.0261 to 0.2036
Cerrado Field	0.2037 to 0.2629
Cerrado sensu stricto	0.2630 to 0.3813
Cerrado sensu stricto tending to Cerradão	0.3814 to 0.4405
Cerradão	0.4406 to 0.5589
Mesophilic forest	0.4406 to 0.5589

Source: Adapted from Bitencourt (1997).

To identify permanent preservation areas adjacent to springs, it is necessary to select a phytophysiognomy dense enough to offer a dense vegetation cover on the soil, as a criterion, it was considered as minimum in terms of vegetation density, the formation of Cerradão sensu stricto up to the mesophilic forest, that is, the ND that store a value equal to or greater than 0.2630 indicated the presence of healthy vegetation to compose the APP (Riparian Forests), while values below 0.2630 represented a deficit or absence of vegetation.

To highlight only the pixels that contained the vegetation within the given limit, it is necessary to reclassify the raster file calculated by NDVI to redefine through a predetermined parameter, changing the original image (Fitz, 2008). The native QGIS algorithm "Reclassify by table" was used to enforce the pre-established parameters. Any pixel with a value equal to or greater than 0.2630 will be reclassified to 1, while any pixel with a value less than 0.2630 will be reclassified to 0.

The product of the execution of this algorithm under these parameters is a black and white raster file that allows a better visualization of the places where there is the presence of vegetation considered sufficient to compose a riparian forest. The raster file was cropped to within the boundaries of the APPs of the watercourses and vectorized to form a single polygon-shaped file, allowing area calculation and visualization by overlay in KML format in Google Earth Pro.

4 RESULTS AND DISCUSSIONS

The use of GIS tools is fundamental as well as the critical analysis, both quantitative and qualitative, of the modification suffered by natural vegetation or implanted by human interference. Given the difficulty of access and resources to capture images of extensive areas, the use of satellite images is crucial in the analysis of vegetation on large scales, compensating for the low accuracy when compared to the use of Unmanned Aerial Vehicles (UAVs) with attached optical sensors.

To quantify the presence of vegetation in the legal zones of permanent preservation areas, the use of remote sensing data proved to be effective for monitoring these areas intercepted by linear projects, allowing the identification of changes in vegetation cover (Tagliari; Batista, 2020).

All the polygons used were acquired free of charge in different databases on the internet, using as a reference to start the analysis, the data made available by public agencies such as the State Geoinformation System (SIEG) and the Environmental Geographic Information System (SIGA-GO). As for the raster files, they are obtained through official portals that periodically publish the images captured by the satellite sensors.

Free access to this data allows the promotion of research and analysis carried out by private or public initiatives, for-profit or not, establishing an active community for environmental analysis. These databases play a key role in the selection and conservation of green areas for biodiversity, as they provide consistent data on land use and vegetation cover (Wiens *et al*., 2009).

The results obtained in the diagnosis of the Permanent Preservation Areas (PPAs) of the Meia Ponte River Basin, upstream of the SANEAGO Raw Water Pumping Station in Goiânia, were satisfactory. These reinforce the importance of using remote sensing and geoprocessing techniques for sizing green areas in zones of ecological importance.

Previous studies have already demonstrated the effectiveness of these GIS tools in monitoring vegetation cover and assessing anthropogenic pressure on PPAs (Tagliari; Baptista, 2020; Campos *et al*., 2015; Santos *et al*., 2014). In this context, the incorporation of artificial intelligence methods represents a significant advance, as it expands the ability to classify and interpret orbital images, allowing greater precision in the detection of environmental changes (Maxwell; Warner; Fang, 2018).

The processing of data in a GIS tool, in scientific means, follows protocols so that the experiment is repeatable in other machines. Many of the procedures applied can be simplified as a sequence of actions promoted by the tools through the software's native algorithms. The use of A.I.s allows the automation of these protocols and the understanding of the procedures performed.

This perspective dialogues with Liu (2006) and Wiens *et al*. (2009), which highlight the importance of remote sensing tools applied to environmental and ecological analyses. In addition, considering that the hydrological function of riparian forests is essential for the regulation of the water cycle (Lima; Zakia, 2000; Miranda; Silva; Oliveira, 2010), the use of learning algorithms becomes a promising tool for automating procedures, facilitating more robust environmental diagnoses.

The calculation for the watershed was made considering the resolution of the raster file made available by the TOPODATA project database. The total area of the drainage zone at the point of the SANEAGO Raw Water Pumping Station in Goiânia was 1614.1426 km², approximately 13.25% of the Meia Ponte River basin.

Landsat 8-9 and Sentinel-2 have divergences in their optical sensors, mainly in spatial resolution and spectral resolution. A considerable divergence was identified, which directly interferes in the calculation of the green area present within the watershed, specifically in the legal zone of permanent preservation areas. There was a vegetation difference of 1.47% between the analyses performed on the two satellite images, as shown in Table 3.

Table 3

Pixel reclassification table

Satellite	Total Area (km²)	Percentage of Total Area (%)
Landsat 8-9	58,5666	3,62
Sentinel - 2	82,2799	5,09
Average	70,4232	4,36

Source: The authors, 2026.

There is a limitation of how much the satellite image is able to capture through its sensors, the light emitted by vegetation, this is due to factors such as atmospheric distortions, presence of clouds, spatial resolution of the pixel, physiological stage of the plant, period of drought or rain, and so on. All these factors affect the accuracy of the analysis, distorting the information acquired from reality.

According to Liu (2006), satellite images are indirect representations of the Earth's surface, they are limited to spatial, spectral and temporal resolution. The same author also points out that cloud cover and atmospheric conditions compromise the fidelity of the information. Therefore, we have created a virtual environment that represents reality, even if at a certain distance from reality, to facilitate the interpretation of data that are imperceptible to human senses.

The monitoring of the presence of vegetation is associated with the evaluation of the vigor of the forest population in a given period of analysis, being subject to variations, and which intrinsically depend on the type of phytophysiognomy. In the work of Bitencourt *et al*. (1997), satisfactorily demonstrated that it is possible to identify different phytophysiognomies of the Cerrado, using NDVI classifications.

These classifications became effective for the evaluation of the presence of vegetation in riparian forests in the watershed. (1997) and visualize where forest formations such as gallery forests, cerradão and cerrado sensu stricto are present.

However, the pressure of agriculture is one of the factors in the suppression of riparian forests, which is why it is still a pertinent advance that replaces the existing vegetation with an implanted one, exogenous to the place. In an image classification operation, the areas mixed with gallery forests and cultivation zones appear to be a single continuous area of vegetation in an indistinguishable way.

There is a zone of vegetation contiguous to the springs, which despite having already been filtered using the raster reclassification using the values in Table 4 as a reference, there are still zones where there is this mixture between crops and native vegetation. It is an error considered during the diagnosis of the presence of vegetation, but it requires the development of new methods to perform this separation.

Table 4

Table of areas of the total vegetation of the basin

Satellite	Total Area (km²)	Percentage of Total Area (%)
Landsat 8-9	221,3424	13,71
Sentinel - 2	402,3410	24,92
Average	311,8417	19,31

Source: The authors, 2026.

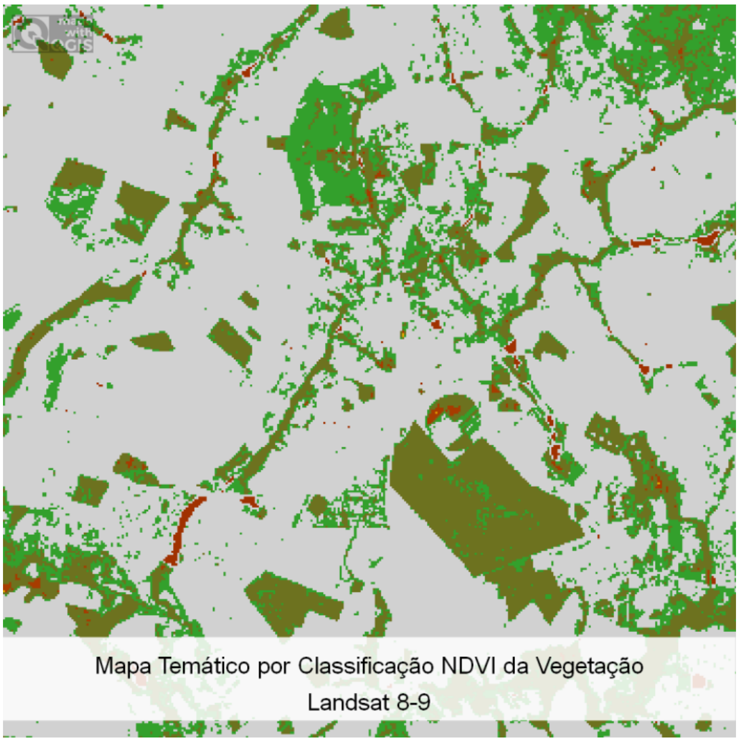
The ability to capture the lengths of electromagnetic radiation reflected by vegetation depends on the intrinsic characteristics of the sensor and its spatial resolution. The significant difference between the areas of vegetation detected by the two satellites is due, in this case, to the spatial resolution, being 30 meters for Landsat 8-9 and 10 meters for Sentinel-2. Therefore, for more accurate analyses, Sentinel-2 has greater accuracy, facilitating the understanding of reality through the virtual environment of the GIS.

The permanent preservation area of the entire hydrographic basin downstream of the EEAB belongs to only 3.62% and 5.09%, analyzed by Landsat and Sentinel-2 respectively. And, compared to the entire vegetated area, classified according to the work of Bitencourt *et al*. (1997), makes up only 26.45% and 20.45%, analyzed by Landsat and Sentinel-2, respectively. The proportion of vegetation by the total area and by the vegetated area provide us with important points to analyze the complexity of the flora system of the watershed.

The amount of vegetated area is notoriously small even if, even considering within these values, the cultivation zones, that is, approximately 70% of this entire area is composed of pastures, easements, reflecting pools or urban areas. The amount of vegetated area is notoriously small even if, even considering within these values, the cultivation zones, that is, approximately 70% of this entire area is composed of pastures, easements, reflecting pools or urban areas. The removal of native vegetation in areas of PPAs of springs, such as gallery forests and wetlands, directly compromises water quality, accelerates river sedimentation and reduces the recharge of underground aquifers (Silva, *et al*., 2010). Figure 1 and Figure 2 clearly represent the difference generated by the difference in the spatial resolution of the image.

Figure 1

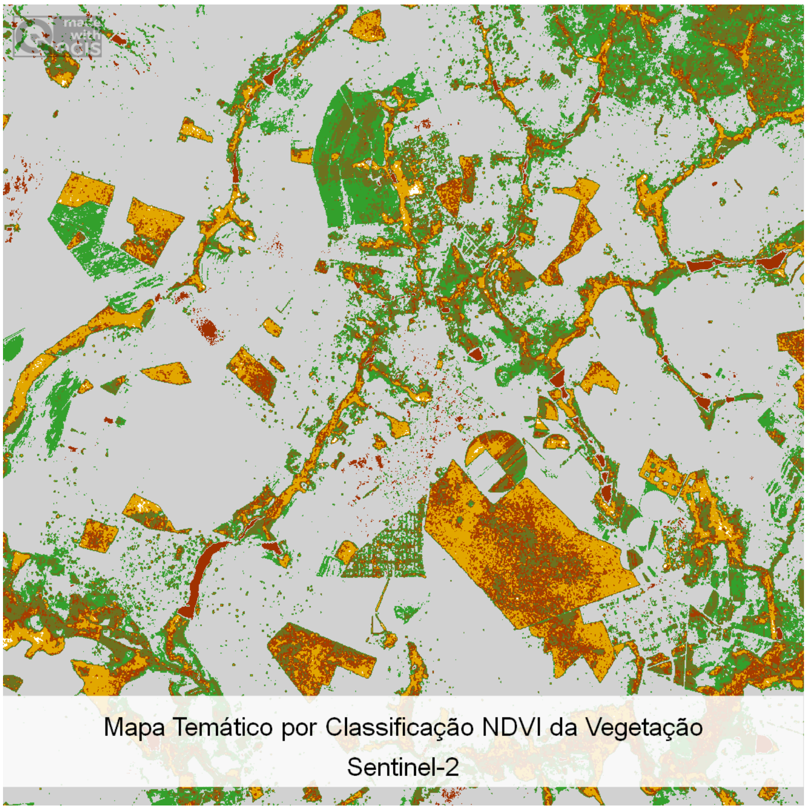
Map cut by NDVI classification from Landsat 8-9



Source: The authors, 2026.

Figure 2

Map cut by NDVI classification from Sentinel-2



Source: The authors, 2026.

It is through the satellite monitoring of the APP that it is possible to diagnose the extent of the areas with absence of vegetation in the APP, although the on-site investigation can directly validate the reality of an enterprise, the evaluation on large scales only takes place through the creation of a virtual environment that allows the complete visualization of these large areas.

Both satellites showed a difference in light capture per square meter due to spatial resolution, this analysis directly interfered in the determination of vegetation per raster pixel. While Landsat offers an image with checkerboard and less fluid zones, where there is little understanding of vegetation continuity, Sentinel-2 allowed for greater precision in places where there is vegetation and at the beginning and end of green spots.

Tables 3 and 4 demonstrate this difference through the quantification per square kilometer of vegetated area through a process of pixel reclassification that uses, as a condition, the work of Bitencourt (1997). However, for large-scale environmental analyses, Landsat can still prove useful for the evaluation of vegetation in large areas, while for research whose objective is a more detailed evaluation, the use of Sentinel-2 is recommended.

This research was conducted considering the possibilities of access to information that is publicly available on the internet through different databases, all the sources cited, manipulated and used are available on the internet. The availability of satellite images by projects such as Landsat and Sentinel-2, for example, made it possible to monitor vegetation cover, enabling the identification of land use conflicts (Copernicus, 2025; Oliveira; Pirajá, 2022).

Currently there are many consultancies that take advantage of satellite images available on the internet to generate marketable products such as charts, maps and technical reports. There is an active search for enterprises for environmental services that are capable of providing remote sensing services for the regularization of environmental liabilities or strategic reallocation of resources on their property.

The study by Tagliari and Baptista (2020) demonstrates how the use of open remote sensing data is effective in detecting interference in APPs caused by large projects, such as railways. Public services such as the CAR require a prior analysis of the rural enterprise through the entrepreneur or consultancy for the analysis and delimitation of vegetation, pastures, cultivation plots, consolidated areas, easements, constructions and so on. Geoprocessing does not depend exclusively on restricted or high-resolution data, but on a well-structured methodology and the initiative of those who analyze.

This research also aimed at a simple and pedagogical development, using tools such as artificial intelligence and Python scripts that are accessible to the public, of a methodology for the production of cartographic products whose purpose is the classification, identification and evaluation of the presence of vegetation in a study area. Information, in turn, is data modified and transformed so that it is readable and interpretable by a user.

Irregular land occupation in permanent preservation areas can be identified through these accessible tools and methodologies, as shown by Campos *et al.* (2015) and Santos *et al.* (2014), who used geoprocessing to evaluate land use conflicts in micro-basins. Therefore, the inspection carried out at a distance through satellite images is a means of identifying areas with liabilities.

However, the identification and regularization will only occur through the receptive action of the secretariats (municipal or state) of the environment, something that is already facilitated given the accessibility of the inspectors regarding the daily updated satellite images and tools such as UAVs and transportation for displacement. The identification of these environmental liabilities occurs only after the entry of a request to open a process to regularize some activity of the requesting entrepreneur within a rural property.

Only after the prior analysis of the documentation and opening of the process will there be a diagnosis of the project to identify these liabilities, provided that, in the opening of this request, there is as a criterion the detection of irregular areas and zones. With this detection, the entrepreneur is obliged to carry out the appropriate measures so that the environmental liabilities are regularized.

It is a passive, retrograde and slow logic of environmental monitoring. The result of this is the ineffectiveness of public environmental agencies in carrying out adequate maintenance of ecological zones that need attention, conservation, regeneration and preservation. Environmental regularization and preservation of the environment depends on the denunciation or self-denunciation of an environmental activity. Meanwhile, the irregular suppression of vegetation, especially riparian forests, progresses exponentially to the benefit of the passive and linear detection of these irregularities by the competent bodies.

With the amendment of the forest code by Law No. 12,727/2012, there were concerns about the flexibility of the protection of water resources, which made the active role of society in terms of environmental surveillance even more relevant (Brasil, 2012; Silva *et al*., 2010). Environmental inspection can be decentralized and collaborative, especially in these cases in which official agencies demonstrate slowness or passivity in the face of projects that are awaiting licensing.

Remote sensing creates a virtual and organic environment between different people, who carry out different research and activities, from the creation of cartographic products and distribution of this information. In an ideal world, this information, in the form of cartographic products or shapefiles or rasters for example, could be shared in a large public database that would be continuously fostered by the users themselves.

This would reduce the time of analysis and data collection for different users of geoprocessing. In addition, in this scenario, there would be more and more recent and updated data for different objectives, integrating a virtual ecosystem that constantly seeks to map reality through optical sensors installed in drones or satellites. The possibility of cross-referencing public data, such as those from the IBGE (SIDRA and Environmental Economic Accounts), with satellite images, allows for an integrated analysis of the pressure on natural resources, especially in areas of agricultural and livestock expansion (Ana, 2022; Rivero *et al*., 2009).

Who, in principle, identifies the first environmental liabilities, are the consultancies or private analysts who carry out a prior analysis under criteria established by legislation, of the activities of their clients. With the information in hand, it is already possible to prepare a regularization strategy to be presented to the environmental agency.

Regularizations will only occur if, after prior analysis, the entrepreneur decides to continue with the administrative process to acquire his desired authorization, under the condition of regularizing his liabilities. The initiative to unify all these geoprocessing agents in a single virtual environment for sharing and cross-referencing data is reserved for public agencies, thus increasing the contact between public and private agents and increasing the amount of tax.

The data obtained can subsidize environmental regularization actions via the Rural Environmental Registry (CAR) and Environmental Recovery Programs (PRA), contributing to territorial planning and the conservation of water resources.

5 CONCLUSION

The present work demonstrated the relevance of the use of geotechnologies, especially remote sensing for the evaluation of Permanent Preservation Areas (PPAs) in the Meia Ponte River Basin downstream of the SANEAGO Raw Water Pumping Station in Goiânia.

The analysis of the images from the Landsat and Sentinel-2 satellites made it possible to accurately map the river's tributaries and identify the presence and absence of vegetation contiguous to the springs, within the legally protected strips. The identification of the vegetation was possible through the classification of the image by NDVI index, highlighting the pixels that were contemplated by the class linked to a dense vegetation.

Sentinel-2 was able to be more accurate in identifying vegetation throughout the APP zone of the watershed using the same classification criteria. Through the development of a simple and efficient methodology, using data from public databases as its main resources, any user of open source GIS is able to replicate the procedures for identifying vegetation around APPs in other watersheds. This study reinforces the need for more effective and integrated public policies that encourage the restoration of native vegetation and promote the sustainable management of water resources.

ACKNOWLEDGMENTS

I thank, above all, Olorum, who allowed the necessary enlightenment for me to see the entire trajectory until I could reach this moment. For having given me strength when there was nowhere else to sustain myself. For having taught me to have love in every action applied to this world.

I thank all those I love in the bottom of my heart, especially my parents Anegleyce Teodoro Rodrigues and Jefferson Luiz Clemente de Oliveira, who offered me all the material, emotional and mental resources to make my graduation a reality.

I thank the Terreiro Casa Espírita Anjo Ismael, which offered me the hope, strength and faith necessary to sustain this journey, through love.

I thank all those who, throughout my career, helped me, supported me and motivated me in some way throughout my graduation and the construction of my TCC.

I also thank Leonardo de Campos Lopes for being my tutor in order to transform me into the professional I am today and for having introduced me to the entire universe of my area of expertise.

REFERENCES

Alencar, E. (2024). Histórias do mangue da Guanabara. Instituto Mar Urbano.

Alongi, D. M. (2014). Carbon cycling and storage in mangrove forests. Annual Review of Marine Science, 6, 195–219. https://doi.org/10.1146/annurev-marine-010213-135020

Bitencourt, M. D., et al. (1997). Identificação de fisionomias de cerrado com imagem índice de vegetação. In Anais do 3º Congresso de Ecologia do Brasil (pp. ?–?). Universidade de Brasília.

Brasil. (1988). Constituição da República Federativa do Brasil de 1988. Presidência da República. http://www.planalto.gov.br/ccivil_03/constituicao/constituicao.htm

Brasil. (2012a). Lei nº 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa. Diário Oficial da União. http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm

Brasil. (2012b). Lei nº 12.727, de 17 de outubro de 2012. Altera a Lei nº 12.651, de 25 de maio de 2012, que dispõe sobre a proteção da vegetação nativa. Diário Oficial da União.

Brasil. Agência Nacional de Águas e Saneamento Básico. (2022). Contas econômicas ambientais da água no Brasil: Uso da água na agricultura de sequeiro e irrigada (Boletim do SNIRH, n. 3).

Brasil. Ministério do Meio Ambiente. (2023). Plano de Ação para Prevenção e Controle do Desmatamento e das Queimadas no Bioma Cerrado — PPCerrado.

Campos, M. de, et al. (2015). Geoprocessamento aplicado no conflito do uso do solo em Áreas de Preservação Permanente na microbacia do Córrego Três Barras – Botucatu (SP). Energia na Agricultura, 30(4), 378–382.

Carvalho, I. A. de. (2019). O papel das matas ciliares na conservação do solo e água. Biodiversidade, 3(18), 171–179.

Copernicus. (2020). Sentinel-2 – Documentation. https://documentation.dataspace.copernicus.eu/Data/SentinelMissions/Sentinel2.html#sentinel-2-level-2a-top-of-canopy-toc

Crestana, S., Reichardt, K., & Silva, W. L. C. (1993). Atributos físicos de solos com diferentes culturas sob rotação e sob monocultura. Revista Brasileira de Ciência do Solo, 17(1), 71–77.

Cubas, M. G., & Taveira, B. D. de A. (2020). Geoprocessamento: Fundamentos e técnicas. Intersaberes.

Ferreira, N. C. de F., et al. (2019). O papel das matas ciliares na conservação do solo e água. Biodiversidade, 3(18), 171–179.

Fitz, P. R. (2008). Geoprocessamento sem complicação. Oficina de Textos.

Hollanda, M. P., Campanharo, W. A., & Cecílio, R. A. (2012). Manejo de bacias hidrográficas e a gestão sustentável dos recursos naturais. In D. M. Lima et al. (Orgs.), Atualidades em desenvolvimento sustentável (Vol. 1, pp. 57–66). Suprema Gráfica e Editora Ltda.

Lima, G. S. A. de, Ferreira, N. C., & Ferreira, M. E. (2018). Modelagem da perda superficial de solo para cenários de agricultura e pastagem na Região Metropolitana de Goiânia. Revista Brasileira de Cartografia, 70(4), 1510–1536.

Lima, W. P., & Zakia, M. J. B. (2000). Função hidrológica da vegetação florestal (2a ed.). EdUSP.

Liu, W. T. L. (2006). Aplicações de sensoriamento remoto. Ed. UNIDERP.

Maxwell, A. E., Warner, T. A., & Fang, F. (2018). Implementation of machine-learning classification in remote sensing: An applied review. International Journal of Remote Sensing, 39(9), 2784–2817.

Miranda, R. A. C., Oliveira, M. V. S., & Silva, D. F. (2010). Ciclo hidrológico planetário: Abordagens e conceitos. Geo UERJ, 1(21), 109–123.

Nepomuceno, P. L. M. (2012). Diagnóstico de áreas de preservação permanente com utilização de técnicas de sensoriamento remoto e SIG: Estudo de caso Bacia Hidrográfica do Ribeirão Gomeral [Monografia de especialização, Universidade Federal do Paraná].

Novaes, R. D. (2022). Avaliação das áreas de preservação permanente – APPs presentes nos cursos d'água e nas nascentes da bacia de captação do rio Meia Ponte – BCRMP, Estado de Goiás [Dissertação de mestrado, Universidade Estadual de Goiás].

Oliveira, A. K. M., & Pirajá, R. V. (2022). Análise multitemporal da cobertura vegetal na Bacia Hidrográfica do Córrego Ceroula, Mato Grosso do Sul. Interações, 23(4), 997–1011.

Rivero, S., et al. (2009). Pecuária e desmatamento: Uma análise das principais causas diretas do desmatamento na Amazônia. Nova Economia, 19(1), 41–66.

Santana, D. P. (2003). Manejo integrado de bacias hidrográficas (Documentos, 30). Embrapa Milho e Sorgo.

Santos, J. R. dos, et al. (2014). Avaliação da adequação da ocupação do solo em Áreas de Preservação Permanente (APPs). Revista Irriga, 19(2), 333–344.

Silva, J. M. C., et al. (2010). Impactos potenciais das alterações do Código Florestal nos recursos hídricos. Biota Neotropica, 10(4), 45–50.

Silveira, A. L. L. (1993). Ciclo hidrológico e bacia hidrográfica. In C. E. M. Tucci (Org.), Hidrologia - Ciência e aplicação (pp. ?–?). ABRH: EDUSP.

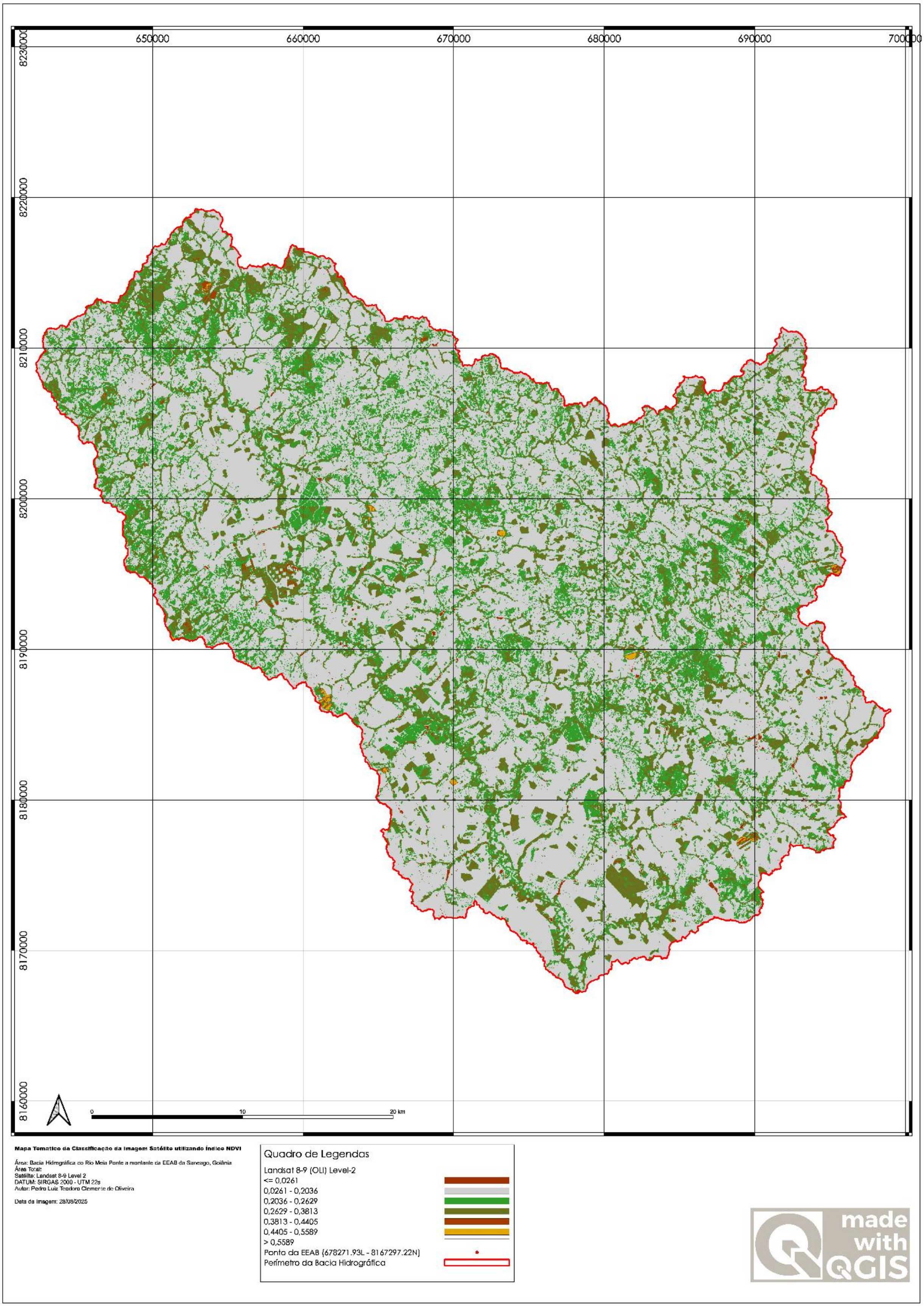
Tagliari, P. D., & Baptista, G. M. de M. (2020). Monitoramento de áreas de preservação permanente (APP) interceptadas pela Ferrovia Norte-Sul em um trecho do estado de Goiás/Brasil por meio de dados de sensoriamento remoto. Revista Brasileira de Geomática – RBGeo, 8(3), 181–201.

United States Geological Survey. (2025). Landsat Satellite Missions. https://www.usgs.gov/landsat-missions/landsat-satellite-missions

Wiens, J., et al. (2009). Selecting and conserving lands for biodiversity: The role of remote sensing. Remote Sensing of Environment, 113, 1370–1381.

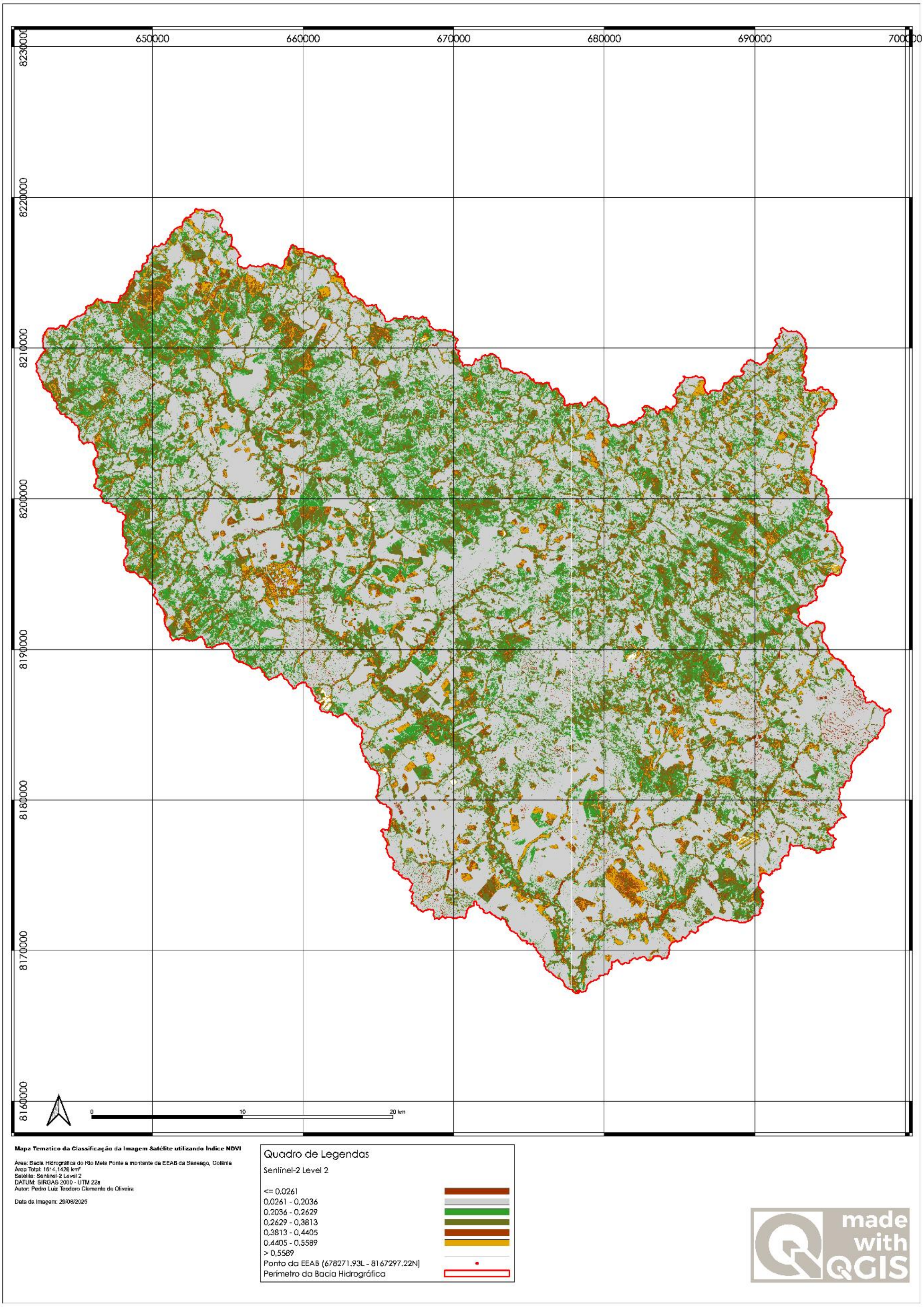
APPENDIX

Figure 3



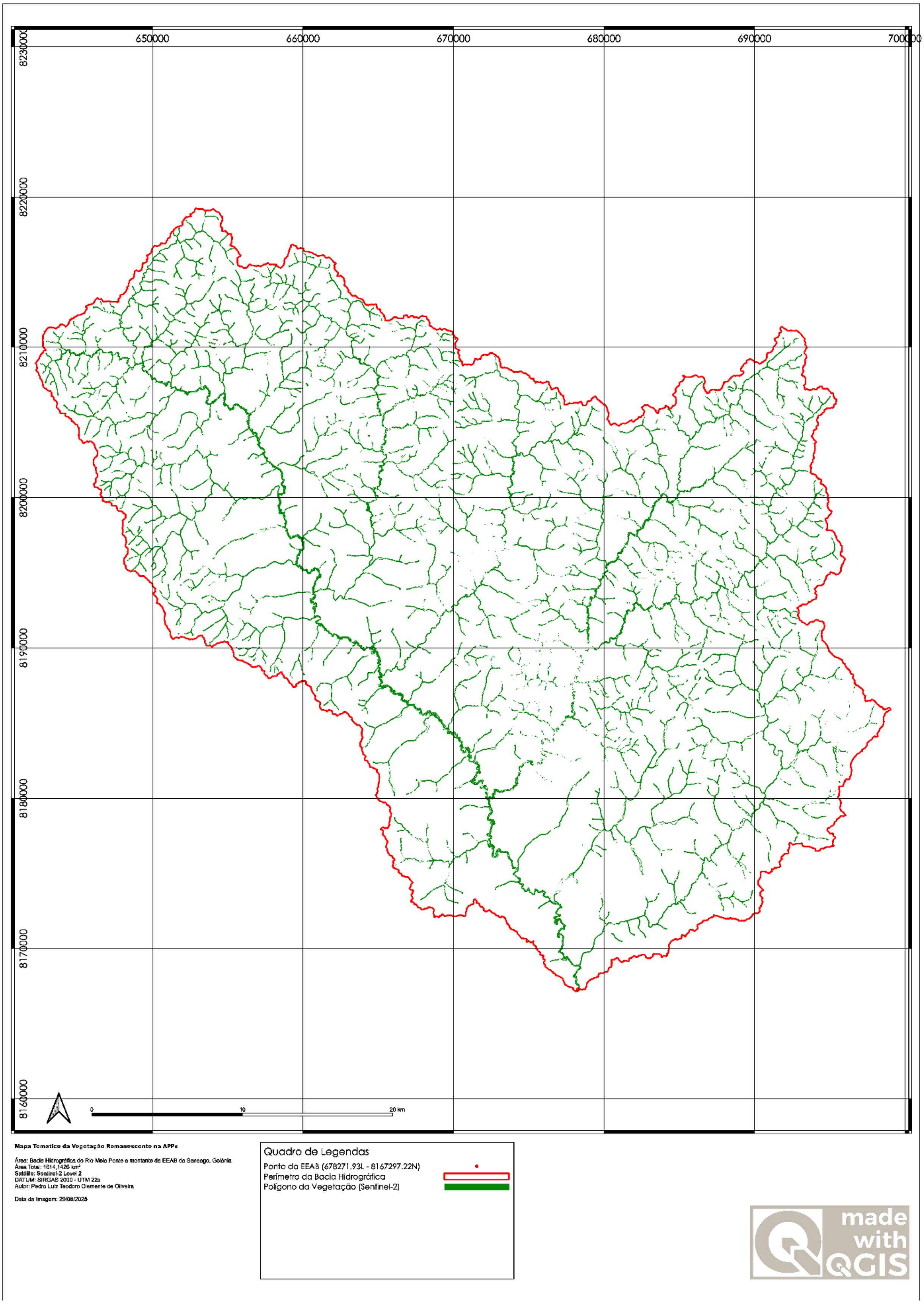
Source: Authors.

Figure 4



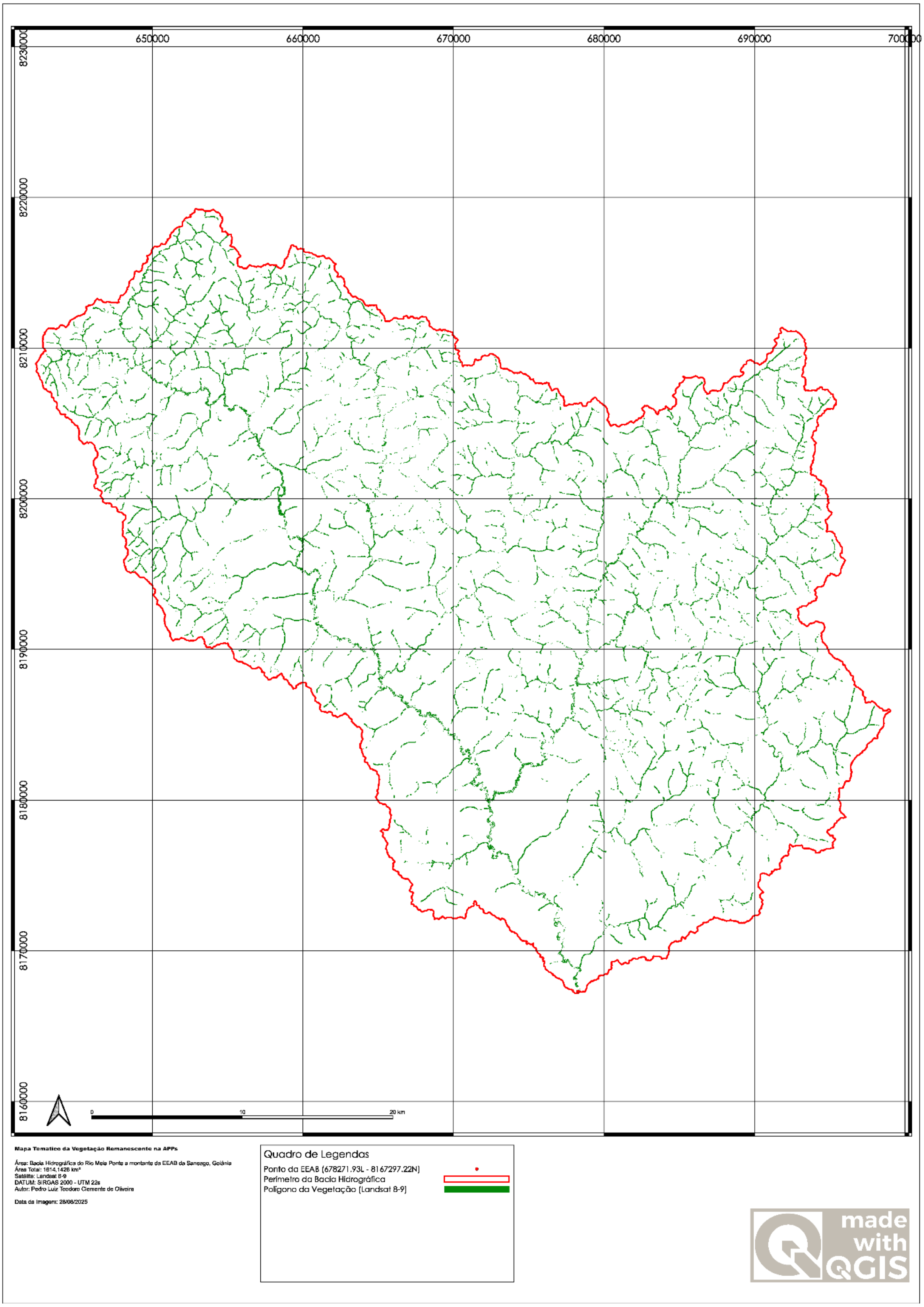
Source: Authors.

Figure 5



Source: Authors.

Figure 6



Source: Authors.