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ÍNDICE RADIOMÉTRICO NDVI EM ÁREA DE PRESERVAÇÃO PERMANENTE OBTIDO POR MEIO DE AERONAVE REMOTAMENTE PILOTADA*

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1 RESUMO

O emprego das Aeronaves Remotamente Pilotadas (RPA) como ferramenta no sensoriamento remoto possibilitou uma plataforma operante no mapeamento agrícola e ambiental com elevada precisão. O objetivo deste estudo consistiu na análise do Índice de Vegetação por Diferença Normalizada (NDVI) em Área de Preservação Permanente (APP) ripária para elaboração de mapas temáticos por meio de aerofotogrametria e fotointerpretação, com maior detalhamento da vegetação devido à altíssima resolução espacial alcançada com o uso de imagens coletadas por RPA em trecho do rio Lavapés, dentro dos limites da Fazenda Experimental Lageado no município de Botucatu, SP. As imagens foram obtidas por meio dos sensores MAPIR Survey3W RGB e Survey3W NIR/InfraRED, embarcados em RPA multirrotor 3DR SOLO. Para construção dos ortomosaicos RGB e NDVI, as imagens foram processadas no aplicativo Pix4Dmapper. O resultado do NDVI proporcionou transição bem nítidas entre os alvos bióticos (vegetação) e os alvos abióticos (corpo d'água), e também entre a própria vegetação, possibilitando a distinção da vegetação de porte arbóreo, com maior vigor vegetativo, em relação à vegetação de porte herbáceo. As imagens com elevada resolução espacial coletadas por RPA, demonstraram flexibilidade de utilização, possuindo elevado potencial para o mapeamento da dinâmica da paisagem e a resposta espectral da vegetação.

Palavras-chave: índice de vegetação, fotogrametria aérea, veículo aéreo não tripulado, sensoriamento remoto.

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NDVI RADIOMETRIC INDEX IN PERMANENT PRESERVATION AREA OBTAINED THROUGH REMOTELY PILOTED AIRCRAFT

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2 ABSTRACT

The use of Remotely Piloted Aircraft (RPA) as a tool in remote sensing has enabled an operant platform in agricultural and environmental mapping with high precision. This study aimed to analyze the Normalized Difference Vegetation Index (NDVI) in riparian Permanent Preservation Areas (APP) for elaboration of thematic maps through aerophotogrammetry and photointerpretation, with greater detail of vegetation due to the very high spatial resolution achieved with the use of images collected by RPA in a stretch of Lavapés river, inside the domains of Lageado Experimental Farm in the municipality of Botucatu, SP. The images were obtained through MAPIR Survey3W RGB and Survey3W NIR/InfraRED sensors, aboard a 3DR SOLO multirotor RPA. For the construction of RGB and NDVI orthomosaics, the images were processed using Pix4Dmapper app. The NDVI result provided a clear transition among biotic targets (vegetation) and abiotic targets (waterbody), and also among the vegetation itself, with greater vegetative vigor, making possible the distinction of arboreal vegetation, in relation to herbaceous vegetation. The images with high spatial resolution collected by RPA, demonstrated flexibility of use, having high potential to mapping landscape dynamics and the spectral response of vegetation.

Keywords: vegetation index, aerial photogrammetry, unmanned aerial vehicle, remote sensing.

3 INTRODUCTION

Remote sensing is based on the interaction between natural electromagnetic radiation emitted by the Sun or by an artificial energy source, captured by sensors embedded in devices such as satellites, airplanes, and remotely piloted aircraft (RPAs). The latter is hailed as the most recent innovation in geoprocessing, following the creation of the *global positioning system* (GPS). This makes it possible to obtain a set of information about a given object without the need for direct contact with it (JENSEN, 2015; TAGLIARINI, 2017).

In this way, it is possible to acquire data related to a target through solar radiation reflected or absorbed by it on the scanned surface, without the existence of direct contact between the sensor and the target to be studied, analyzing only its spectral behavior (PEREIRA; SILVA; PAMBOUKIAN, 2016).

The recent development of remote sensing techniques using satellite and RPA imagery has provided a new range of mapping tools, making this activity faster and easier (ALFONSO-TORREÑO et al., 2019). Digital photogrammetry through aerial mapping via RPAs, adjusted by *Global Navigation Satellite Systems* (GNSS) and based on *real-time kinematic* (RTK), is an efficient mapping technique because it allows for the graphic representation and quantification of information with high spatial resolution, generating accurate orthorectified images that allow coverage of relatively large areas in a short period of time, as they allow for the generation of rapid estimates (RODRIGUES et al., 2021; RODRIGUES, 2020).

Compared with other photogrammetry platforms, the main advantage of RPAs is their logistics, which allows for expanded temporal resolution and flexible data updates. This allows for the production of high-resolution, high-value products, enabling projects, particularly in agricultural and environmental mapping. This enables the acquisition of remote sensing products, such as images, with high quality, speed, and accuracy. However, their use depends on the region's characteristics, the type of analysis to be employed, the frequency with which information is collected, and the equipment's monetary value. Therefore, surveyors can determine which remote sensing technique best suits their project.

A remote sensing methodology used for environmental monitoring in studies of land use and occupation at a given location is the calculation of radiometric indices or vegetation indices, which are prepared from the spectral behavior of biotic and abiotic targets, representing their activities (TAGLIARINI, et al., 2021; TAGLIARINI, 2020). Vegetation indices consist of dimensionless radiometric measurements obtained by verifying the spectral behavior of vegetation and indicate the photosynthetic activity of vegetation, percentage of vegetation cover, chlorophyll content in plants, biomass accumulation, and development stage, among other characteristics (JENSEN, 2015).

One of the most widely used and widespread radiometric indices globally for vegetation mapping, particularly in agronomic and environmental studies, is the normalized difference vegetation index (NDVI), which consists of the ratio of the difference in reflectivity of the near-infrared and red bands to the sum of these reflectivities (ROUSE; HAAS; SCHELL, 1974). The NDVI is an indicator with a range from -1 for areas without vegetation, impermeable areas, and areas with bodies of water to 1 for vegetation with leaves whose metabolic and physiological functions peak. The greener, more nourished, healthier, and well-supplied the plant is, the greater the absorption of red light and the higher the infrared reflectance (PEREIRA; SILVA; PAMBOUKIAN, 2016).

The NDVI is an index widely used in monitoring seasonal and temporal profiles of agricultural and forestry activities to analyze, in different types of vegetation, the longevity of the development period (maturation, flowering, fruiting and harvesting), as well as the moments of interventions in management due to changes in spectral behavior found in these types of vegetation (PONZONI; SHIMABUKURO; KUPLICH, 2012).

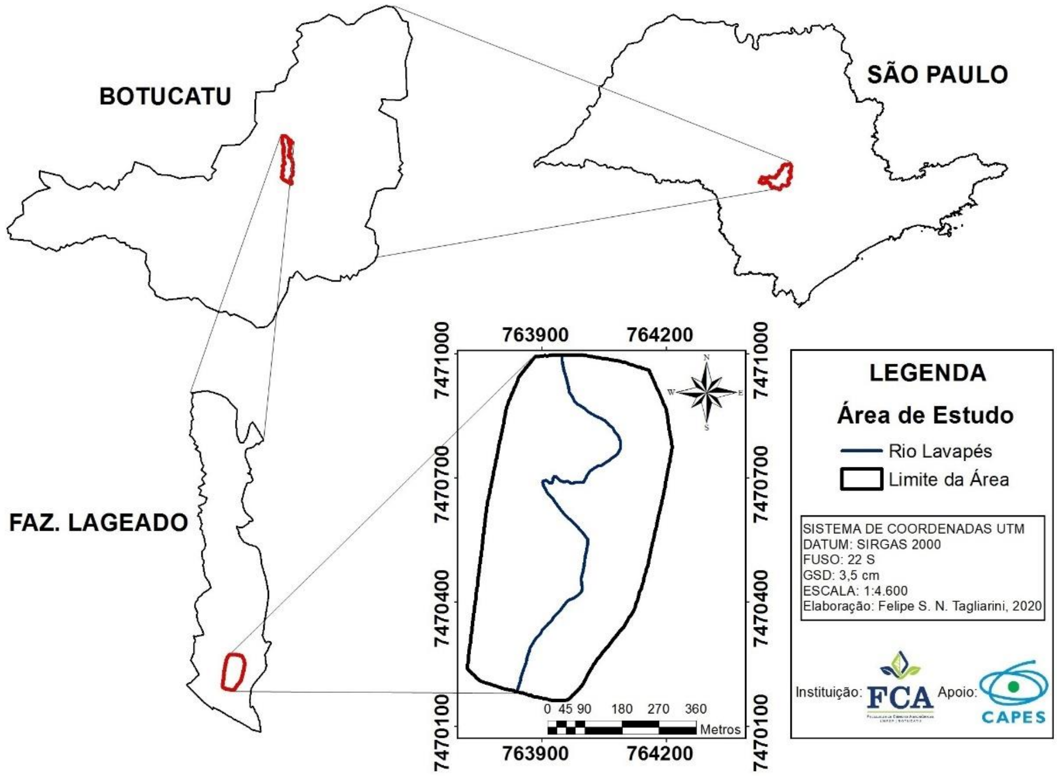
This work aimed to obtain the radiometric index NDVI in a riparian permanent preservation area (APP) for the creation of thematic maps through aerial photogrammetry and photointerpretation, with the aim of accessing greater detail of the vegetation through the spatial resolution achieved with the use of digital images collected by the RPA in a section of the Lavapés River, located within the limits of the Lageado Experimental Farm, Botucatu, SP.

4 MATERIALS AND METHODS

4.1 Description of the study area

The study area is located at the Lageado Experimental Farm, which belongs to the School of Agricultural Sciences (FCA) and the School of Veterinary Medicine and Animal Science (FMVZ) of São Paulo State University (Unesp). It is located near the FCA Department of Rural Engineering, in a stretch of the Lavapés River Permanent Preservation Area. This region is located on the border between the urban and rural perimeters of the municipality of Botucatu (Figure 1), which is located in the Central-West region of the state of São Paulo and is located between UTM coordinates 763700 to 764300 East and 7470100 to 7471000 South, Time Zone 22 S, Zone K, with a total area of 30.35 ha.

Figure 1. Location of the study area at the Lageado Experimental Farm



The climate of the region, according to the Köppen climate classification, for the municipality of Botucatu, is of the Cwa type, being defined as humid subtropical with dry and cold winters and rain in the summer, with greater intensity. The average annual temperature is 21.5 °C, with an average annual precipitation of 1385.5 mm, according to data from the Lageado Meteorological Station, belonging to the Faculty of Agricultural Sciences (FCA/UNESP) of Botucatu, SP.

The soils present in the study area, according to Carvalho, Espíndola and Paccola (1983), with information and updated according to the pedological classification proposed by Embrapa (2018), are Dystrophic Red Latossol (LVd), Dystrophic Red Latossol (LVdf), Dystrophic Red Nitossol (NVd1), Dystrophic Red Nitossol transition to Dystrophic Red Latossol (NVd2), Dystrophic Litholic Neosol basalt substrate (RLd), and Dystrophic Fluvic Neosol (RYbd).

The remaining native vegetation at the Lageado Experimental Farm belongs to the Atlantic Forest biome. Because the study area is located in the Lavapés River permanent preservation area (APP), the native vegetation is semideciduous seasonal forest, which originates from riparian vegetation that also runs parallel to the river. It has a rich and diverse floristic composition, encompassing species from botanical families such as *Fabaceae*, *Bignoniaceae,* and *Arecaceae* (ANTONELLI; BATISTA, 2019).

4.2 Operating platform, *software* and flight parameters

Aerial images of the study area were obtained via a multirotor (quadrirotor) RPA, model 3DR Solo from the American manufacturer 3D Robotics (Figure 2).

Figure 2. RPA quadrotor 3DR Solo

MAPIR Survey3W RGB (0.380 to 0.740 µm) and MAPIR Survey3W NIR/InfraRED (0.725 to 1.10 µm) sensors, both with resolutions of 12.1 *Megapixels* (Figure 3), were used to record aerial images of the study area.

Figure 3. MAPIR sensors: Survey3W RGB and Survey3W NIR/InfraRED

An AOC *tablet, model TABLET breeze™ 8"*, was also used to assist in controlling the RPA and installing telemetry *software* for the flight mission. The free *ground station software* Mission Planner 1.3.7 was used for mission planning, defining the route and flight path and providing telemetry between the RPA and the platform during the mission.

The MAPIR *calibration ground target* was used for the calibration and reflectance correction of the sensors

(MAPIR Survey3W RGB and MAPIR Survey3W NIR/InfraRED).

The Pix4Dmapper photogrammetry and photointerpretation application was used to generate orthomosaics in red–green–blue (RGB) and infrared compositions, georeferencing, separating the red current from the RGB image, and calculating and generating the NDVI radiometric index. ArcGIS 10.5 *software* was used for all vectorizations and for finalizing and generating the *layout* of the maps obtained in the study.

A total of five hundred eighty-nine (589) images were obtained for the construction of each orthomosaic. The images were collected in a single day on July 17, 2018. The stipulated flight speed was 7 m/s (25.2 km/h). The images have both frontal (*overlap*) and lateral (*sidelap*) overlaps of 80.00%, since the higher the overlap rate is, the lower the probability of error and the greater the guarantee that data will not be missing during processing, despite the need for more flight lines to cover the area. The stipulated flight height was 70 m, which is within the regulatory agency's regulations (NATIONAL CIVIL AVIATION AGENCY, 2017).

A ground sample distance (GSD) of 3.5 cm was adopted for all images obtained, corresponding to the study area and the flight altitude employed, thus aiming for higher image resolution and following the standards and guidelines of the National Civil Aviation Agency (ANAC). The SIRGAS 2000 datum, which is the official horizontal datum of Brazil, was adopted for all maps obtained and developed in this study.

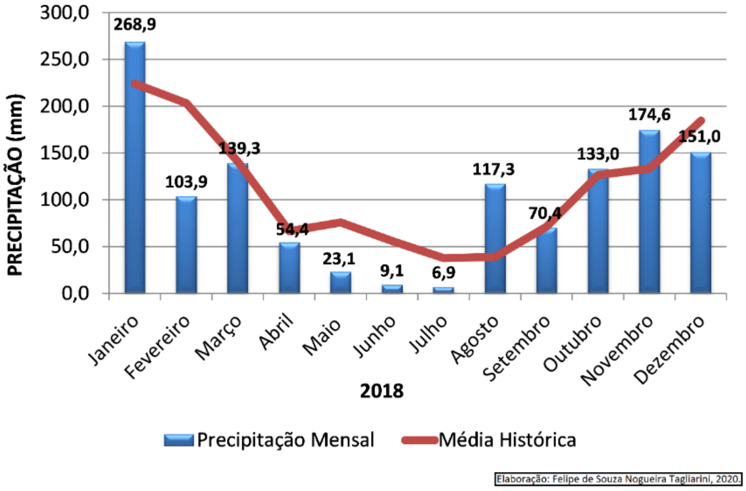
4.3 Meteorological data

images of the study area used to obtain the NDVI were collected during the dry/winter period. This time of year was chosen because it is the best time to observe the difference between tree and herbaceous species, making it easier to distinguish them, as observed by Sartori et al. (2009), Demarchi, Piroli, and Zimback (2011), França et al . (2013), Albuquerque et al . (2014), Machado et al . (2014), and Tagliarini et al. (2017), since herbaceous plants are more sensitive to dry periods.

To choose the best period to obtain the images, an analysis of the historical precipitation profile in the municipality of Botucatu-SP (1988 - 2018) was carried out, observing rainfall data obtained from the Lageado Meteorological Station.

The Botucatu region, São Paulo, has a regular annual rainfall profile, with December, January, and February being the wettest months and the dry season occurring from April to the end of August (Figure 4). July 2018 was the driest month of the year, with the lowest precipitation, in line with the municipality's historical rainfall average, and was used as a basis for estimating the period in question.

Figure 4. Rainfall behavior in 2018 and historical profile of Botucatu, SP (1988 - 2018)



4.4 Calibration of the reflectances of RGB and NIR/InfraRED mosaics

RPA images, which are low-altitude multispectral products obtained from suborbital platforms, do not require corrections for atmospheric influences caused by the scattering, absorption, and refraction of electromagnetic energy. Unlike satellite images, RPA images require only reflectance corrections from their sensors, which are corrected via the *calibration ground target* (CGT) (TAGLIARINI, et al., 2021).

The CGT is a ground-level target with known reflectance curves and can be captured from any angle during flight because of its diffuse reflectance properties. Reflectance corrected by the CGT improves the normalization of aerial images and, consequently, the generation of mosaics and the vegetation index, in this case, the NDVI (TAGLIARINI, 2020).

4.5 Normalized difference vegetation index (NDVI)

Using images from the best period for analysis and subsequent acquisition of the predominant currents of the red (obtained from the RGB image) and near-infrared (obtained from the NIR/InfraRED image) spectra, these collected images were grouped to form an orthomosaic. The *Index Calculator function* of the Pix4Dmapper application was used to obtain the radiometric index (NDVI).

The radiometric index NDVI was obtained via calculation (Equation (1)) based on Rouse, Haas and Schell (1974) and Tucker (1979). After the NDVI was obtained, it was divided into classes by the scale of index values according to Tagliarini (2020) and Tagliarini et al. (2021).

$$NDVI = \frac{(\rho NIR - \rho RED)}{(\rho NIR + \rho RED)} \quad (1)$$

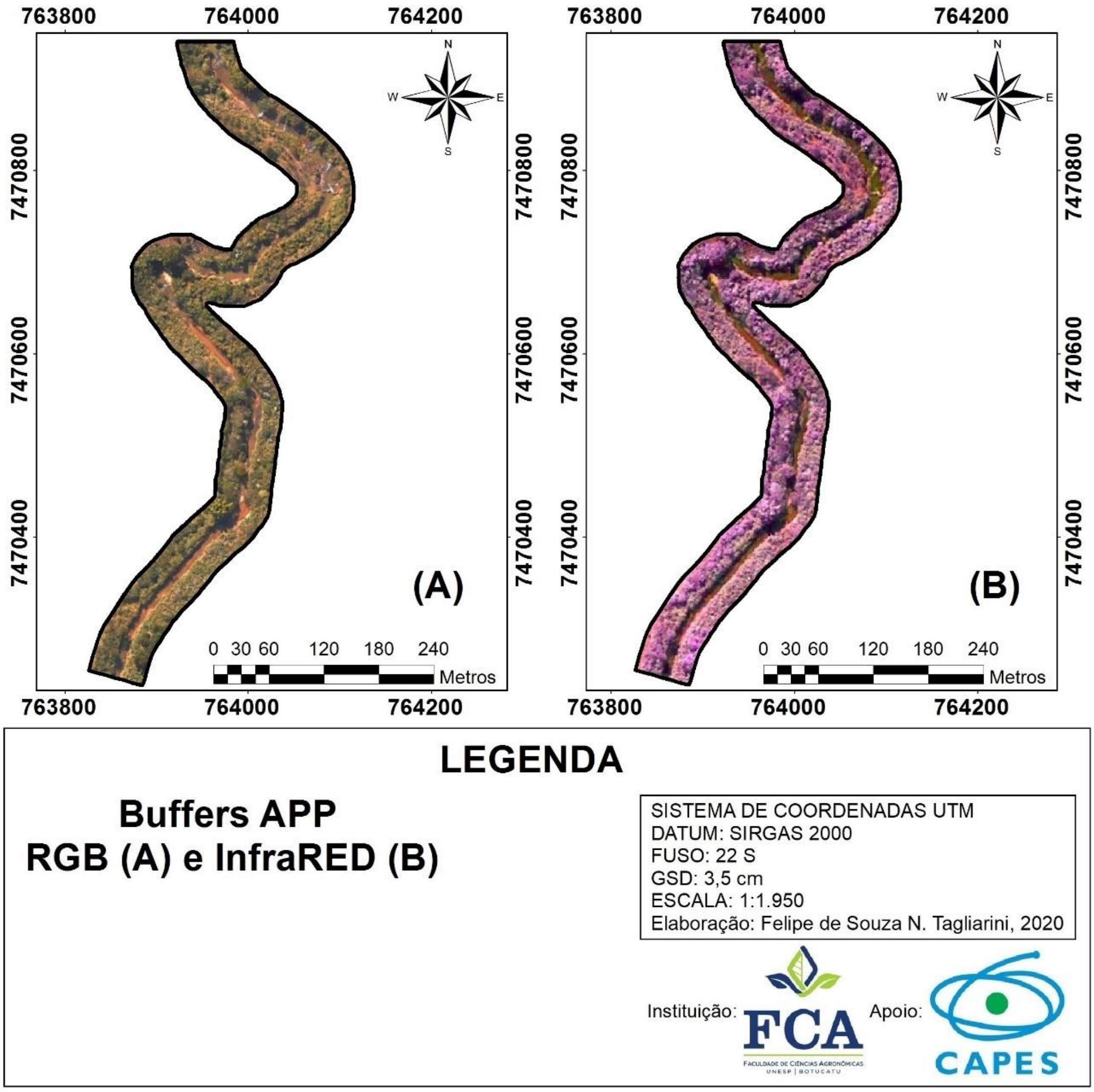
where NDVI is the normalized difference vegetation index (dimensionless); ρNIR corresponds to the near-infrared reflectance (0.725--100 µm); and ρRED corresponds to the reflectance in the visible red spectrum range (0.630--0.700 µm).

5 RESULTS AND DISCUSSION

5.1 Analysis of the riparian APPs in the study area

For a more detailed analysis of land use and occupation in the riparian APP of the study area, a 30 m *buffer was created* in the RGB and infrared orthomosaics (Figure 5), since this section of the Lavapés River is less than 10 m wide , with a total area of 5.96 ha, in accordance with current forestry legislation, Law No. 12,651, with the modifications proposed in Law No. 12,727 of 2012, which defines the size of the APP strips according to the width of the surface water body (BRASIL, 2012a; BRASIL, 2012b).

Figure 5. Riparian APP *buffer* in the RGB (A) and infrared (B) directions of the study area



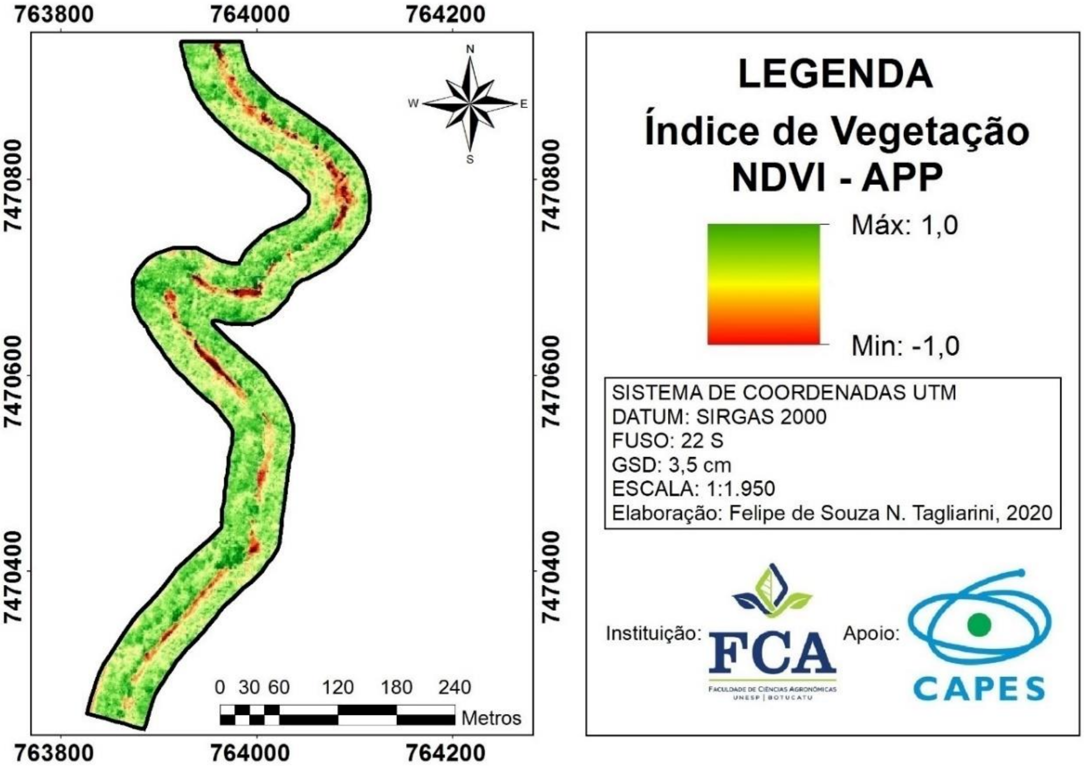
In this way, it is possible to distinguish the different patterns and types of land use, as well as vegetation, more easily because of the different native, exotic and agricultural species present in the APP region of the study area.

The near-infrared orthomosaic of the riparian APP *buffer* makes the distinction between the riparian vegetation of the Lavapés River and other land uses in the study area even more evident because of the spectral behavior of the tree, shrub, and herbaceous vegetation in the region, as this vegetation primarily reflects the radiation spectrum in the near-infrared range. Therefore, it was possible to identify the existence or otherwise inappropriate land use and occupation in the APP region simply by observing the spectral behavior of the vegetation.

5.2 NDVI as an analysis tool for riparian APPs

The response sensitivity obtained by the radiometric index NDVI (Figure 6) demonstrated that a considerable proportion of APPs, in a spatial analysis of the 30 m *buffer*, were occupied irregularly or had vegetation forms considered to be unsuitable for the constitution of riparian vegetation in the study area.

Figure 6. Riparian APP *buffer* effect on the NDVI in the study area



The Lavapés Riverbed presented negative NDVI values very close to -1, exhibiting a spectral behavior very typical of this abiotic target, since, unlike plant formations (biotic targets), this (target) does not reflect the wavelength in the near-infrared range but rather absorbs it, similar to the results obtained by Sartori et al. (2009), Demarchi, Piroli and Zimback (2011), Rodrigues and Rodrigues (2012), Barbosa, Carvalho and Camacho (2017), Tagliarini et al. (2017), Tagliarini (2020) and Tagliarini et al. (2021), who demonstrated that the NDVI radiometric index, despite being designed for the detection of vegetation aspects due to the wavelengths used for its calculation, also clearly identifies the water bodies present in digital images.

This range of negative vegetation index values, in addition to the riverbed region, may correspond to areas such as polygonal target geoforms corresponding to the presence of water bodies in general, soils with surface water outcrops, bare soils, soils with erosion processes, rocky outcrops, and impermeable areas such as roads, buildings, and rural constructions. The spatial distribution of negative values (between 0 and -1) occurs in a dispersed or clustered manner throughout the riparian APP strip, as shown in Table 1, following the classification proposed by Tagliarini (2020) and Tagliarini et al. (2021).

Table 1. NDVI values of riparian APPs and their representativeness.

NDVI value	Classes	Area (ha)	Area (%)
< 0.00	Riverbed	0.89	14.93
0.00 - 0.20	Spectral mixing	0.40	6.75
0.20 - 0.40	Less dense herbaceous vegetation	1.10	18.51
0.40 - 0.60	Dense herbaceous vegetation	1.34	22.48
0.60 - 0.80	Less dense tree vegetation	2.18	36.64
0.80 - 1.00	Dense tree vegetation	0.05	0.69
TOTAL	**-**	**5.96**	**100.00**

Positive reflectance values, ranging from 0.40 to 0.80, indicate a higher rate of photosynthetic activity, with a predominant presence of denser tree vegetation, indicating adequate ground cover for riparian vegetation in the APP zone. Values between 0.00 and 0.40 indicate a lower rate of photosynthetic activity, with a spectral mixture of areas without vegetation or with less dense vegetation cover, such as shrubs and mainly herbaceous vegetation, in agreement with the values obtained by Matese et al. (2015) used the RPA for a viticulture survey, in which the authors also found targets presenting spectral mixture, in addition to the presence of areas without vegetation, hindering the correct identification of the class present in the NDVI value.

5.3 Land use in the riparian APPs of the study area

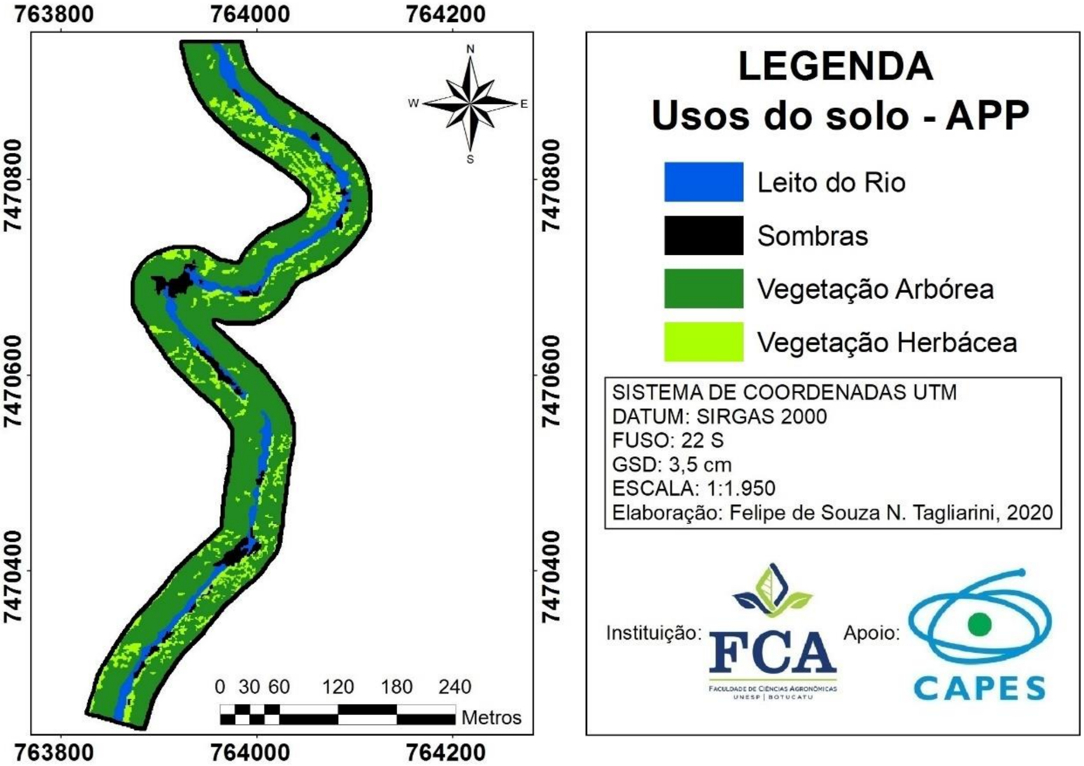
On the basis of the RGB and NDVI orthomosaics, it was possible to identify four land use classes in the riparian APPs of the study area (Table 2). The most comprehensive class corresponds to "Arboreal Vegetation", with a total area of 4.16 ha (69.89%), composed of shrubs and small and large trees . The second most comprehensive class is "herbaceous vegetation", with a total area of 0.90 ha (15.14%), which is composed of herbaceous extracts, mainly grasses , followed by the "riverbed" class, with an area of 0.64 ha (10.69%), and, finally, the "shadening" class, which corresponds to a total area of 0.26 ha (4.28%).

Table 2. Land use classes in the riparian APP of the study area.

Classes of uses	Area (ha)	Area (%)
Riverbed	0.64	10.69
Shadows	0.26	4.28
Tree Vegetation	4.16	69.89
Herbaceous Vegetation	0.90	15,14
TOTAL	**5.96**	**100.00**

Practically 3/4 of the total area of the riparian APP (Table 2 and Figure 7) of the study section of the Lavapés River is composed mainly of tree-sized individuals and is therefore within the limits of current forestry legislation (Law 12,651/2012 and Law 12,727/2012).

Figure 7. Land uses present in the riparian APPs of the study area



However, observing one of the images referring to the RGB orthomosaic (Figure 8), of the stretch of the Lavapés River with a width of less than 10 m , it can be seen that part of the 30 m margin referring to the riparian APP, which should contain only native vegetation of tree size in the riparian strip of the study area, presents the presence of ground cover (grasses, other forms of herbaceous vegetation and fragments of agricultural area) that do not comply with current forestry legislation (Law 12.651/2012 and Law 12.727/2012), which does not guarantee the full protection of the APP in these stretches.

Figure 8. Incorrect land use in the Lavapés River permanent preservation area

6 CONCLUSION

The great advantage of collecting images via RPA is that it can be used at any time of the year, both in dry and rainy periods, without problems with cloud cover, and allows images to be taken at the frequency required (low temporal resolution), in addition to generating products with a high degree of detail and allowing centimetric spatial resolution.

The NDVI radiometric index allows the identification of both biotic (vegetation) and abiotic (water body) targets via the use of visible red and near-infrared spectra in the calculation, since biotic targets reflect these spectra, whereas abiotic targets absorb them, thus allowing great contrast between both.

The high spatial resolution images obtained by the RPA demonstrated the flexibility of use and can be used both for visual analysis (RGB orthomosaic) and for obtaining a radiometric index such as the normalized difference vegetation index (NDVI), thus having the potential for mapping landscape dynamics and the spectral behavior of vegetation.

The data obtained by this study can also contribute to the improvement and refinement of the techniques used in environmental monitoring because of the reliability of the results, thus contributing to inspection and compliance with Brazilian forestry legislation.

7 ACKNOWLEDGMENTS

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