BURNED AREA AND FUEL LOAD MAPPING IN A PROTECTED AREA SITUATED IN THE BRAZILIAN CERRADO, USING LINEAR SPECTRAL UNMIXING MODEL

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ABSTRACT

In order to evaluate the effects of fire in the Indigenous Land denominated Xerente, situated in the Brazilian State of Tocantins, the linear spectral unmixing model (LSUM) was applied in orbital images of the optical satellite Sentinel-2/MSI to estimate the dry and green vegetation, soil and burned areas fractions that constitute study area. The imagery was processed in the free software SNAP, provided by the European Space Agency – ESA. The modeling captured an extent of ~54,000 hectares (32%) of burned areas. The fuel load mapping detected ~55,000 hectares (33%) of the dry vegetation element, ~47,000 hectares (28%) of green vegetation and ~10,000 hectares (6%) of the soil component. The modeling's results were considered suitable when compared to photographs taken *in loco*. Therefore, the LSUM was considered effective in the evaluation of fire management efforts in the Brazilian Cerrado.

Key words **—** Sentinel-2, Indigenous Land, integrated fire management, free software, spectral response.

1. INTRODUCTION

The Cerrado is a diverse but highly threatened tropical savanna-like biome, covering over 2 million km², which represents approximately 24% of the total area of Brazil [1]. Fire management is an important issue in the Brazilian Cerrado, since both high intensity fires and complete fire suppression can reduce the biodiversity in this biome [2]. Indeed, the understanding of these two variables on ecosystem function is fundamental to a satisfactory establishment of public policies focusing on natural resource management [3]. Brazilian governmental institutions (such as the Brazilian Institute of Environment and Renewable Natural Resources – IBAMA and the Chico Mendes Institute for Conservation of Biodiversity – ICMBio) therefore implemented prescribed burnings as part of integrated fire management in protected areas of the Cerrado, aiming to reduce the area and severity of forest fires [4].

The objective of this study is to evaluate the efficiency of the linear spectral unmixing model on the detection of the amount and distribution of fuel loads and burned areas in an Indigenous Land situated in the Brazilian State of Tocantins. The proposed method demands relatively low computer requirements for image processing and uses a free software, intending to assist the decision-making in the fire management process and to assess the effects of fire in the landscape.

2. MATERIAL AND METHODS

2.1. Study Area

The Xerente Indigenous Land (IL) is located in the municipalities of Tocantínia and Pedro Afonso, in the Brazilian State of Tocantins. The territory comprises 167.542,105 hectares, as stated in the Federal Decree of homologation nº 97.838 of June 16, 1989. According the RadamBrasil Project (1983), the main vegetation in the indigenous territory is classified as Arborized Savannah, with or without gallery forest. The type of climate is tropical; the average annual precipitation is 1766 mm; the average yearly temperature is 26.9 °C (CPTEC/INPE, 2018).

2.2. Acquisition and pre-processing of the Sentinel-2 imagery

In this study were used two images from the satellite Sentinel-2/MSI, 22LGQ and 22LHQ, both from August 16, 2018 (Figure 1).

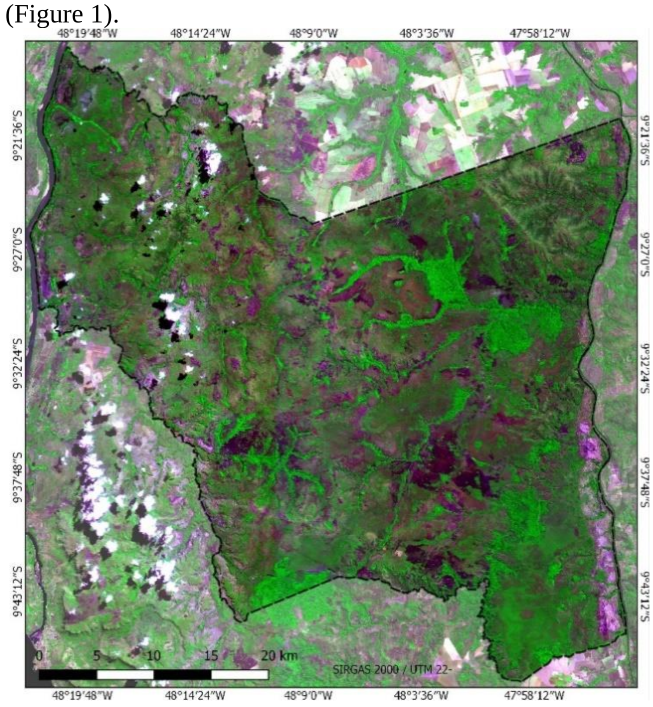

Figure 1: Sentinel-2 images of the Xerente IL (R-4 G-8 B-2).

The spectral data were submitted to an atmospheric correction process, conducted in the software Sentinel Application Platform – SNAP (version 6.0.0), more specifically through the plugin Sen2Cor 2.5.5 (Sentinel 2 atmospheric Correction), both freely available in the European Space Agency – ESA website. The resulting product is an image in the Bottom-Of-Atmosphere reflectance, optionally generating terrain and cirrus correction images.

Additionally to the three visible and the NIR (near infra-red) bands, which have a 10 m resolution, the three Red Edge bands were also used, as well as the two SWIR (short wave infra-red) bands and the NIR-2 (or NIR plateau) band, which have a 20 m spatial resolution. Therefore, the spatial resolution was homogenized from 20 m to 10 m using the nearest neighbor resampling [5,6], through the SNAP tool "resampling", which allows the user to resample a multi-size product (in which bands are of different sizes and/or resolutions) to a single-size product.

2.3. Linear spectral unmixing model (LSUM)

Pixels with spectral mixture correspond to a function between the sensor's spatial resolution and the spatial scale of the surface components, where each pixel spectrum represents a linear combination of a finite number of pure elements [4].

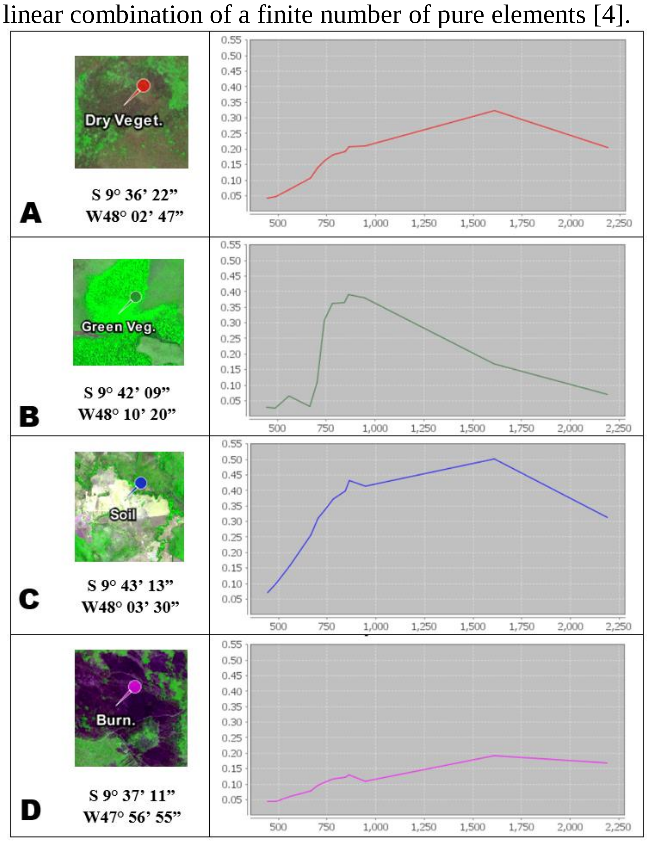

Figure 2: Location and spectral curves of the selected *endmembers*: (A) Dry (non-photosynthetic) Vegetation, (B) Green (photosynthetic) Vegetation, (C) Bare Soil and (D) Burned Area.

The spectral characteristics of each pixel of the satellite image can be interpreted as a linear combination of the spectral signatures of each element present in the mixture, in which each pixel (that can assume any value inside the scale of grey level – 2^n bits) contains information about the proportion and the spectral characteristic of each element [7] (Figure 2).

In the current study, the elements (or "*endmembers*") that constitute the spectral mixture utilized to determinate the dry vegetation, green vegetation, bare soil and burned area fractions were directly selected from the Sentinel-2 satellite image 22LHQ from September 25, 2017 (peak of the dry season).

According Shimabukuro & Ponzoni (2017), the linear spectral unmixing model is a system of equations, with one equation for each band of the proposed sensor, and can be generically described as (equations 1 to 11):

$$r_i = a_{1.1}\, x_1 + a_{1.2}\, x_2 + (...) + a_{i.j}\, x_j + e_i \qquad \text{(Eq. 1)}$$

$$\text{or } r_1 = a_{1.1}\, x_1 + a_{1.2}\, x_2 + a_{1.3}\, x_3 + a_{1.4}\, x_4 + e_1 \qquad \text{(Eq. 2)}$$

$$r_2 = a_{2.1}\, x_1 + a_{2.2}\, x_2 + a_{2.3}\, x_3 + a_{2.4}\, x_4 + e_2 \qquad (...)$$

$$r_3 = a_{3.1}\, x_1 + a_{3.2}\, x_2 + a_{3.3}\, x_3 + a_{3.4}\, x_4 + e_3$$

$$r_4 = a_{4.1}\, x_1 + a_{4.2}\, x_2 + a_{4.3}\, x_3 + a_{4.4}\, x_4 + e_4$$

$$r_5 = a_{5.1}\, x_1 + a_{5.2}\, x_2 + a_{5.3}\, x_3 + a_{5.4}\, x_4 + e_5$$

$$r_6 = a_{6.1}\, x_1 + a_{6.2}\, x_2 + a_{6.3}\, x_3 + a_{6.4}\, x_4 + e_6$$

$$r_7 = a_{7.1}\, x_1 + a_{7.2}\, x_2 + a_{7.3}\, x_3 + a_{7.4}\, x_4 + e_7$$

$$r_8 = a_{8.1}\, x_1 + a_{8.2}\, x_2 + a_{8.3}\, x_3 + a_{8.4}\, x_4 + e_8$$

$$r_9 = a_{9.1}\, x_1 + a_{9.2}\, x_2 + a_{9.3}\, x_3 + a_{9.4}\, x_4 + e_9$$

$$r_{10} = a_{10.1}\, x_1 + a_{10.2}\, x_2 + a_{10.3}\, x_3 + a_{10.4}\, x_4 + e_{10} \qquad \text{(Eq. 11)}$$

where:

r_i = the average spectral reflectance for the spectral band *i*;

$a_{i.j}$ = the spectral reflectance of the element *j* in the pixel (*endmember*) for the spectral band *i*;

x_j = the proportion of the element *j* in the pixel;

e_i = the error for the spectral band *i*.

The proportion of each element inside the pixel are estimated by the method of the Constrained Least Squares, which minimizes the sum of squared errors by the following function (equation 12):

$$F = \sum e_i^2 \qquad \text{(Eq. 12)}$$

In the current study, the algorithm Linear Spectral Unmixing – Fully Constrained of the software SNAP/ESA, which uses an iterative procedure to solve the constrained least square equations. The option "fully constrained" guarantees that the sum of the endmembers abundances equals 1, and abundance values cannot be less than zero.

3. RESULTS

The resulting product of the linear spectral unmixing model are the fraction images, one for each selected component, which represents the proportions of the elements in the spectral mixture [5,8] (Figure 3). The radiometric resolution of Sentinel-2 is 12 bits, which allows a range of 0 to 4095 grey levels. Considering that the response of each pixel varies between 0 and 1, to a spectral response = 0, the equation result will be the darkest pixel of the fraction image. On the other hand, if the spectral response is 4095, the result will be the brighter pixel of the fraction image, which equals 1.

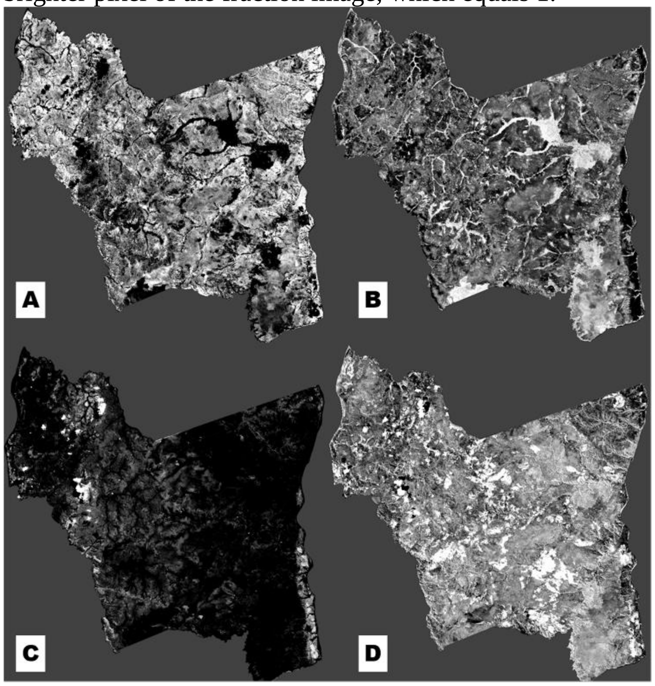

Figure 3: Resulting fraction images: (A) Dry Vegetation, (B) Green Vegetation, (C) Soil and (D) Burned areas.

In August 17 and 18, 2018, photographs were taken *in loco* (Figure 4). Using their geographic coordinates as a reference, the pixel values of the linear spectral unmixing model results are displayed in the Table 1:

Table 1: Photographs' location and respective results:

Photo	Coordinates	Dry Veg.	Green Veg.	Soil	Burn
A	S9° 25' 18.2" W48° 01' 10.1"	0.25	0.09	0.19	0.47
B	S9° 21' 27.2" W47° 56' 40.3"	0.51	0.12	0.15	0.22
C	S9° 21' 24.4" W47° 54' 35.9"	0.52	0.05	0.16	0.26
D	S9° 29' 06.6" W47° 59' 46.0"	0.34	0.24	0.03	0.39
E	S9° 32' 22.5" W48° 03' 44.3"	0.09	0.00	0.18	0.73
F	S9° 40' 22.0" W48° 09' 36.2"	0.00	0.04	0.25	0.71
G	S9° 38' 02.6" W48° 00' 48.7"	0.14	0.04	0.08	0.73
I	S9° 36' 12.0" W47° 56' 01.9"	0.03	0.01	0.50	0.46
J	S9° 36' 24.1" W47° 56' 01.2"	0.00	0.00	0.47	0.53

Burned area values appeared in all samples, and its residues can be seen in the photographs taken *in loco*. The dry vegetation was detected in the samples "A", "B", "D", "E" and "G", and its highest value was detected in the sample "C" (52%). The green vegetation did not respond in some cases (samples "E", "I" and "J"), or presented low values (< 9%) for most samples ("A", "C", "F" and "G"); only samples "B" and "D" showed percentages of 12% and 24%, which can be seen in the photographs. The exposed soil was detected in all samples, especially the values of the pixels "I" and "J" (50% and 47%, respectively), which was well demonstrated by the photographs.

Figure 4: Photographs taken in loco (values on Table 1).

The resulting fuel load map for the Xerente Indigenous Land, with the location where the photographs were taken (letters "A" to "I"), can be seen in Figure 5:

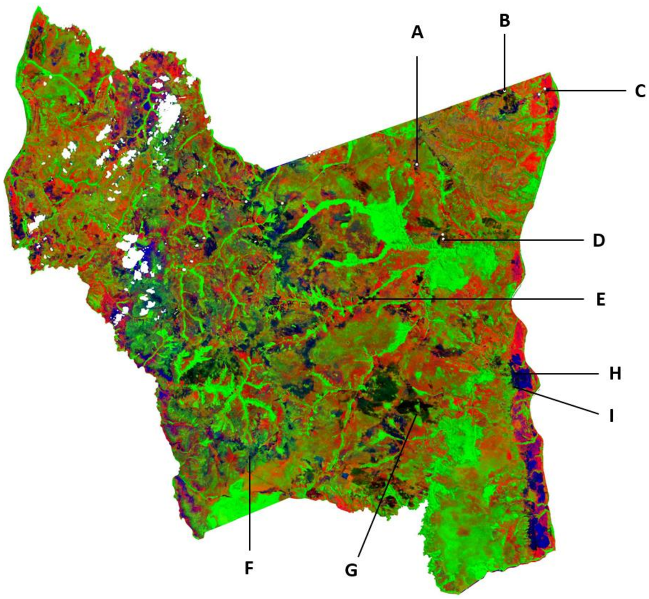

Figure 5: Fuel load map with the colored composition Red=Dry vegetation, Green=Green Vegetation and Blue=Soil; black color represents burned areas and white color represents clouds.

The separation of the four categories based on the spectral behavior of their elements was considered satisfactory, as registered in the photographs taken *in loco* (except the "cloud" category, that was manually selected from the image). In that sense, the following results were obtained in the Xerente Indigenous Land:

Table 2: Area calculation generated with the LSUM:

Element	Dry Veg.	Green Veg	Soil	Burn.	Clouds
Area (hectares)	55,758	47,916	10,244	54,117	2,52
Percentage	33%	28%	6%	32%	1%

4. DISCUSSION

In open savannah ecosystems, the amount of green photosynthetic vegetation and non-photosynthetic vegetation per unit area well represents the present fuel loads [4]. Since prescribed burnings were being conducted in the Xerente IL as a part of integrated fire management program [9], 54,117 hectares of burned area were detected, or 32% of the study area.

The post-fire vegetation regeneration responded mainly as the element dry, non-photosynthetic vegetation. In general, the green, photosynthetic vegetation presented low values (< 9%). According CPTEC/INPE (http://www.inpe.br/queimadas/ciman/area-interesse/11977), it was expected a negative precipitation anomaly for the region since the month of May (Figure 6), which explains the 33% area of dry vegetation detected in the Xerente IL.

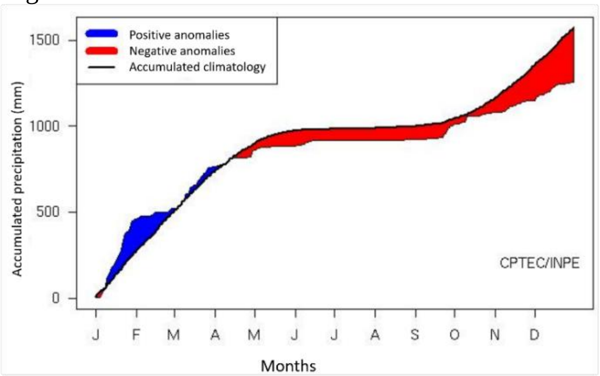

Figure 6: Accumulated precipitation expected for the Xerente IL in 2018 (CPTEC/INPE).

On the other hand, the 28% green vegetation area detected can be explained not only by the sprouting of the post-fire vegetation regeneration, but also by the excerpts of montane semideciduous forest in the study area, as observed by the RadamBrasil Project (1983). Some part of the 6% of soil detected in the modeling is composed of quartz sand, as registered in the photographs "H" and "I".

The linear spectral mixture model uses several spectral bands that are relevant for vegetation studies and proved to be suitable to evaluate the four selected components. Several papers claim that the introduction of the red-edge band (present in the Sentinel-2 data) increases the separability between the land use classes, improving the classification accuracy of vegetation as a component of spectral indices [10], in the discrimination of vegetation species and crops [11] and also to discriminate the severity of the burn [5]. The NIR-2 band (NIR plateau) was also attributed to the generation of spectral curves with a greater level of detail when compared to the Landsat-8 data [6].

5. CONCLUSIONS

The field data demonstrated that the linear spectral unmixing model's results generated from Sentinel-2 satellite images achieved a good description of the selected categories. The 10 m spatial resolution, and also the addition of four spectral bands (three red-edge and one NIR plateau) applied to vegetation studies makes the Sentinel-2 data suitable for the evaluation of fire effects in broad areas. In that sense, the modeling results were considered satisfactory, presenting the detection of 33% of dry vegetation, 28% of photosynthetic active vegetation and 32% of burned areas in a protected area, the Xerente Indigenous Land. The method can be considered promising for the assessment of the impact of fire in the Brazilian Cerrado, and in the assistance of fire management policies.

6. REFERENCES

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