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Comparative Analysis of Multisensor Burned Area Products for the Brazilian Amazon – Region of the APA Triunfo do Xingu

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Abstract

Fires are not natural phenomena of the Amazon rainforest, therefore, they occur due to human activities, and their occurrences have increased in recent years (Costa et al., 2022). This situation requires continuous monitoring of this vast region, especially in areas where agricultural, livestock, mining, and infrastructure activities are located near protected areas (indigenous lands and nature conservation units). One of the conservation units that has recorded the highest increases in deforestation and fire rates is the Triunfo do Xingu Environmental Protection Area (APA Triunfo do Xingu), which since 2018 has registered the highest rates among other conservation units in the Amazon. The present study aims to develop two databases of burned areas from optical and microwave images for the years 2018, 2019, and 2020 for the APA Triunfo do Xingu using Google Earth Engine; then the results are compared with the DETER, MAPBIOMAS and MCD64A1 burned area bases to estimate existing similarities and divergences. This research uses the images of the Sentinel-2/S-2 and Landsat-8/L-8 optical satellites for the month of August of the years 2018, 2019, and 2020, a period of increased occurrences of active fires in the APA Triunfo do Xingu, to generate the burned area database that will serve as a reference for comparison with other burned area databases. Thus, images with spatial resolution, S-2 with 10 meters and L-8 with 30 meters and spectral (red, near, and medium infrared bands), are suitable for generating information with geometric and thematic quality, as the GEE allows the production of pixel mosaics excluding pixels with cloud and cloud shadows. The Sentinel-1/S-1 images used correspond to the VH cross-polarization, which is the most suitable polarization to map burned area than the VV polarization (Prasasti et al., 2020), having 10 meters of spatial resolution, being with speckle noise filter and with backscatter (DB) values. It is noteworthy that the S-1 images correspond to Band C, the wavelength of 5 cm, which reduces the interference of clouds when imaging the surface. In general, the data sets presented many discrepancies between them, which shows the importance of having a methodology focused on specific areas, such as the Amazon, in order to generate a consolidated information base consistent with the reality of the regime of fire in the studied area. The spatial similarity between the data varied little, with the BA-S1 dataset having the highest overlap rates with the reference base of 19% for 2018, 63% for 2019, and 68% for 2020. Among optical sensor data, the BA-S2L8 datasets for the years 2018 and 2020, and BA-MAPBIOMAS, for the year 2019, presented the highest rates, being, respectively, 13% and 56% for BA -S2L8 and 50% for BA-MAPBIOMAS. We emphasize that the overlaps focused on polygons of burned areas smaller than 6.5 hectares, demonstrating the high spatial similarity between the datasets for small fire areas, despite the BA-MCD64A1 not being the best sensor to detect burns more minor than 100 hectares (Katagis and Gitas, 2022).

1. Introduction

Tropical forests are environments of significant ecological importance, mainly due to their high biodiversity and ecosystem services. However, they have suffered global losses estimated at 420 million hectares since the 1990s (FAO and UNEP, 2020) due to degradation processes and land-use conversion. The Amazon Forest suffers from this problem, with deforestation and forest fires as the main elements of degradation and transformation of the forest into other uses (Ometto, Aguiar and Martinelli, 2011; dos Reis *et al.*, 2021).

Fires are not natural phenomena of the Amazon rainforest, therefore, they occur due to human activities, and their occurrences have increased in recent years (Costa *et al.*, 2022). This situation requires continuous monitoring of this vast region, especially in areas where agricultural, livestock, mining, and infrastructure activities are located near protected areas (indigenous lands and nature conservation units). One of the conservation units that has recorded the highest increases in deforestation and fire rates is the Triunfo do Xingu Environmental Protection Area (APA Triunfo do Xingu), which since 2018 has registered the highest rates among other conservation units in the Amazon.

The monitoring of fires by remote sensing is performed by recording the brightness temperature to infer high-temperature points that would be active fires (Yao *et al.*, 2020). In addition to registering active fires, mapping the burned area is of great importance for analyzing the fire risk, carbon emissions rates, and the effects of climate change on ecosystems (Liu, Popescu and Malambo, 2019). Although the first study on mapping burned areas was from 1974 and accurately mapped the limits of fire (Hitchcock and Hoffer, 1974) and, in recent decades, produced several data on burned areas on a global scale, such as GLOBCARBON (Plummer *et al.*, 2006), L3JRC (Tansey *et al.*, 2008), Fire_cci (Chuvieco *et al.*, 2018), currently, there is still much uncertainty in the total area affected by fires (Chuvieco *et al.*, 2019) and the products of burned area present many differences between them, which reveals the need for systematic studies on these differences (Humber *et al.*, 2019).

Due to the dense cloud cover that occurs in tropical regions, it is not easy to record phenomena on the surface of these regions. However, a solution is to use optical sensors with high temporal resolution or to use microwave sensors that have a significant ability to cross clouds according to their wavelength. In addition, monitoring large areas, such as Amazon, requires high computing power to process the data, which is currently possible through the Google Earth Engine/GEE platform, enabling access to an extensive collection of remote sensing images.

Thus, the present study aims to develop two databases of burned areas from optical (Sentinel-2 and Landsat-8) and microwave (Sentinel-1) images for the years 2018, 2019, and 2020 at APA Triunfo do Xingu by Google Earth Engine and then compare with the DETER, MAPBIOMAS and MCD64A1 burned area bases to estimate existing similarities and divergences.

2. Materials and Methods

2.1. Study Area

The Triunfo do Xingu Environmental Protection Area was created in 2006 through State Decree 2612 (PARÁ, 2006) with an approximate area of 1,679,280.52 hectares that covers the municipalities of Altamira and São Félix do Xingu. Its objectives are to protect biological diversity, plan the occupation of the territory, and guarantee the sustainable use of its natural resources. However, due to the advancement of farming and livestock activities, there is a growing disorderly occupation and unsustainable use of natural resources through the continuous increase in deforestation and forest degradation by the use of fire. The main economic activity that permeates APATX is cattle ranching, which exerts pressure for the conversion of forest areas into new pasture areas, and this pressure occurs both inside APATX and in the surrounding forests. This situation is reflected in its indication as the conservation unit with the highest rate of deforestation and presence of hotspots over the last few years.

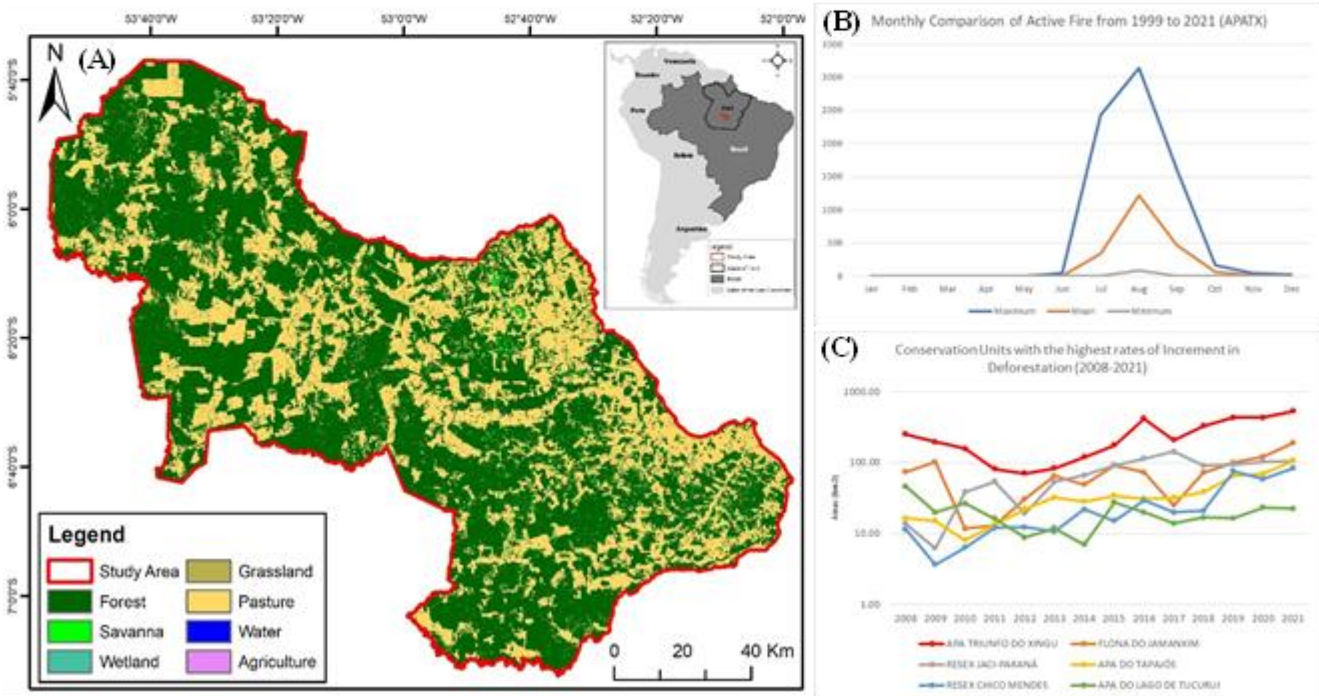

Figure 1- (A) Study Area Location: the APA Triunfo do Xingu located in the southeastern region of the State of Pará/Brazil. Land cover and land use information from the MAPBIOMAS Collection 5 for the year 2020. (B) Monthly comparison of the number of active fires between the years 1999 and 2021 for APATX. Data obtained from the Queimadas Program of INPE/Brazil. (C) Annual comparison of protected areas with the highest deforestation increment rates recorded between 2008 and 2021. Data obtained from the PRODES Program of INPE/Brazil.

2.2. Methodology

The study uses the images of the Sentinel-2/S-2 and Landsat-8/L-8 optical satellites for the month of August of the years 2018, 2019, and 2020, a period of increased occurrences of active fires in the APA Triunfo do Xingu, to generate the burned area database that will serve as a reference for comparison with other burned area databases. Thus, images with spatial resolution, S-2 with 10 meters and L-8 with 30 meters and spectral (red, near, and medium infrared bands) are suitable for generating information with geometric and thematic quality, as the GEE allows the production of pixel mosaics excluding pixels with cloud and cloud shadows.

The Sentinel-1/S-1 images used correspond to the VH cross-polarization, which is the most suitable polarization to map burned area than the VV polarization (Prasasti et al., 2020), having 10 meters of spatial resolution, being with speckle noise filter and with backscatter (DB) values. It is noteworthy that the S-1 images correspond to Band C, the wavelength of 5 cm, which reduces the interference of clouds when imaging the surface.

The processing of the S-2 and L-8 images generated a mosaic of images with minimal presence of clouds and cloud shadows for the month of August of the years 2018, 2019, and 2020. Then, calculate the Burned Area Index (BAI), which highlights pixels with spectral response referring to the absorption of radiation with the biomass burning process. Thus, after identifying the pixels with signs of burning, the image is sliced into determined groups of pixel values and the intersection of the group referring to the burned area with the vectors of active fires obtained from the database of active fires from INPE/Brazil. The intersected pixels are exported as vectors of the burned area class to the GEE database.

The processing of S-1 images starts from the mosaic of images available in each week of the month of August of the year under study. After the mosaic, the change detection processing is performed using the Log-Ratio operator. This logarithmic ratio will highlight the pixels that had a change in values between 2 time periods. Then, I realized the image segmentation process (SNIC), texture index creation (GLCM), and principal component analysis (PCA) to highlight the most significant objects in the images. Subsequently, selected samples for training and classification with the Random Forest classifier. Finally, according to the processing flow below, intersected the classification results with the active fire data and exported the final result as a burned area database.

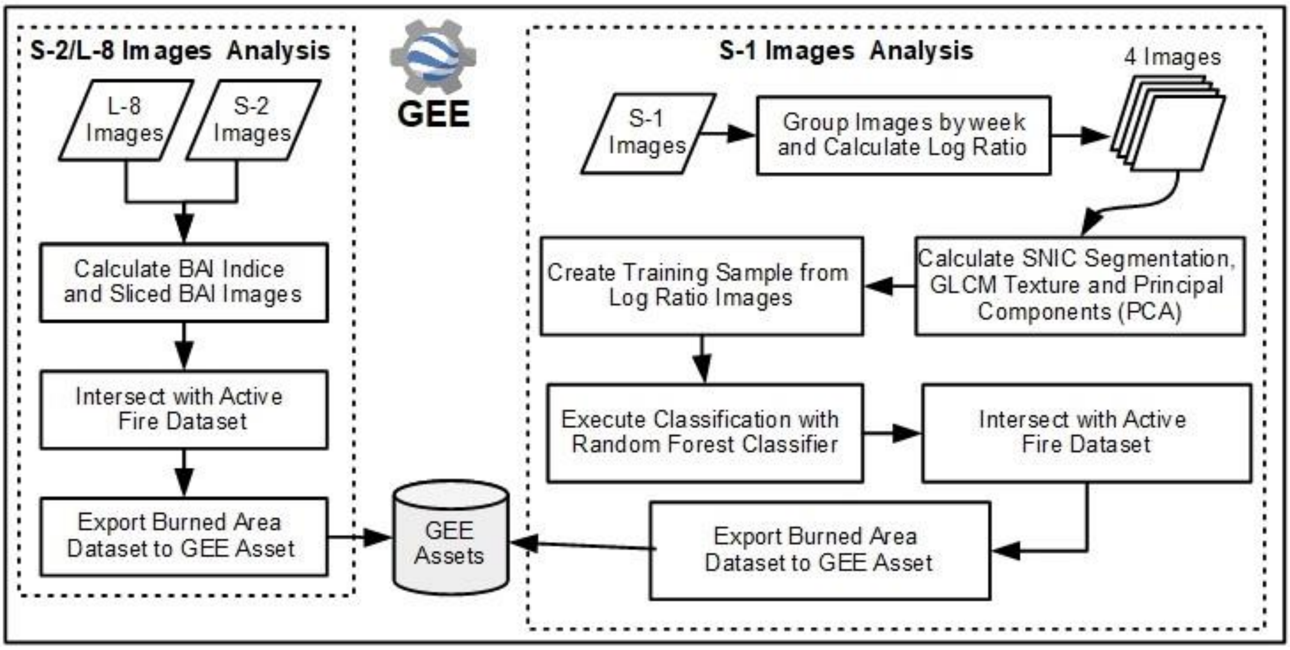

Figure 2 – Images Processing Flow

The burned area data (DETER, MAPBIOMAS, and MCD64A1) are obtained from their electronic addresses and converted into vector shapefile format. It is noteworthy that due to methodological differences between the data, a normalization was carried out with the selection of vectors with a minimum area above 1 hectare. Finally, the comparative analysis evaluated the number of polygons generated in each dataset, their areas, and the overlap rate of the dataset to the reference base, which is the MCD64A1, as the dataset obtained the highest precision for the burned area class at the global level (Padilla *et al.*, 2015).

3. Results and Discussion

The results below demonstrate that for the years 2018, the year with the lowest occurrence of active fires, 2019 and 2020, years that had an increase in active fires, the BA-DETER dataset was the one with the most significant discrepancy in the values of the number of polygons, maximum area and the sum of areas, this is justified because it is a data aimed at alerts and not only to determine the burned area. The reference base (MCD64A1) was different in all the years in the minimum area values, which is due to its spatial resolution being 500 meters. The BA-MAPBIOMAS dataset was the one that had the highest values of the number of polygons in all years, which can be explained by its mapping methodology that operates at the Landsat-8 satellite pixel scale (30 meters). The BA-S1 dataset was the most similar to the reference dataset in terms of maximum area. On the other hand, the BA-S2 dataset was discrepant in all aspects of area in relation to the reference base, which denotes that the difference in spatial resolution has a strong influence on the mapping of the burned area.

Tabela 1- Dataset Area Values

August 2018 Statistics					
	BA - S2L8	**BA - S1**	**BA - DETER**	**BA - MAPBIOMAS**	**BA - MCD64A1**
Number of Polygons	177	46	4	875	102
Minimum Area	1	1	9	1	24
Maximum Area	2344	189	41	1947	237
Sum of Areas	18537	1048	110	17455	4398
Mean of Areas	105	23	27	20	43

	BA - S2L8	BA - S1	BA - DETER	BA - MAPBIOMAS	BA - MCD64A1
August 2019 Statistics					
Number of Polygons	784	1345	153	2048	1861
Minimum Area	1	1	2	1	13
Maximum Area	10066	2375	245	4222	2128
Sum of Areas	152326	36666	4834	69330	93378
Mean of Areas	194	27	32	34	50
August 2020 Statistics					
	BA - S2L8	**BA - S1**	**BA - DETER**	**BA - MAPBIOMAS**	**BA - MCD64A1**
Number of Polygons	772	1471	229	4783	2045
Minimum Area	1	1	1	1	7
Maximum Area	16214	1949	723	3125	1986
Sum of Areas	120419	37585	13877	85217	125222
Mean of Areas	156	26	61	18	61

In general, the data sets presented many discrepancies between them, which shows the importance of having a methodology focused on specific areas, such as the Amazon, in order to generate a consolidated information base consistent with the reality of the regime of fire in the studied area.

The spatial similarity between the data varied little, with the BA-S1 dataset having the highest overlap rates with the reference base of 19% for 2018, 63% for 2019, and 68% for 2020. Among optical sensor data, the BA-S2L8 datasets for the years 2018 and 2020, and BA-MAPBIOMAS, for the year 2019, presented the highest rates, being, respectively, 13% and 56% for BA -S2L8 and 50% for BA-MAPBIOMAS. We emphasize that the overlaps focused on polygons of burned areas smaller than 6.5 hectares, demonstrating the high spatial similarity between the datasets for small fire areas, despite the BA-MCD64A1 not being the best sensor to detect burns more minor than 100 hectares (Katagis and Gitas, 2022).

4. Conclusions

Wildfires are human source phenomena that are present and growing in several areas of the Amazon, being more recurrent in environments naturally prone to fire, such as the cerrado, and areas of expansion of productive activities, mainly livestock and commercial agriculture. The APA Triunfo do Xingu is affected by this dynamic of growth of productive activities and the problems inherent to them, such as deforestation and fires.

The mapping of burned areas in the Amazon still faces many obstacles, especially the limitation of optical sensors in the observing regions with a strong incidence of clouds and the lack of monitoring of the region that uses microwave images, which reduce the problem of limitations of the clouds.

Despite some datasets of burned areas facing the Amazon, there is still a lot of disagreement in the values of burned areas and little spatial similarity between the datasets since we found between 50% and 64% of overlap between some datasets and the reference base. New studies covering longer time intervals and areas with different fire regimes and land use are essential to understanding the limitations that affect the mapping of burned areas. From 2018, the increase in fires inside the APA began, and this problem has worsened since then. Thus, it is of great importance to search for new approaches that allow improving the continuous monitoring of the Amazon, with a focus on deforestation and recording areas burned by fires.

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