Evaluation of Spectral Indices for Identification of Burned Areas Using Sentinel-2 Data in the Savannas das Guianas Ecoregion: A Case Study of Lavrado in Roraima, Brazil

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1. Introduction

Forest fires represent one of the greatest threats to terrestrial ecosystems worldwide, with devastating consequences for biodiversity, climate, and human communities (Aragão, 2023). In the Guianan savannas ecoregion, located in the Brazilian Amazon, this issue assumes particular relevance due to a combination of factors such as seasonal tropical climate, the presence of fire-adapted vegetation, and increasing human pressure on natural resources (Lovejoy and Nobre, 2018).

The Guianan Savannas ecoregion, situated in the Brazilian Amazon, represents a diverse and unique mosaic of landscapes. Extending across parts of the states of Pará, Amapá, and Roraima, this region is a true life refuge, harboring an unparalleled wealth of species and unique habitats (Barbosa et al., 2007). Amidst this abundance, the Lavrado occupies about 19.29% of the State of Roraima and stands out for its distinctive landscape, characterized by rocky outcrops, low vegetation, and a flora adapted to the unique conditions of this environment (Ab'Sáber, 2003; Carvalho et al., 2020). The Lavrado is more than just a landscape; it is a dynamic and resilient ecosystem shaped by centuries of interactions between fire, climate, and biodiversity.

Periodic burnings are an intrinsic part of this natural cycle, playing a crucial role in the regeneration and maintenance of the health of local ecosystems (Barni et al., 2022). However, fire dynamics in the Lavrado are complex and often influenced by human activities such as deforestation, agriculture, and livestock farming. These anthropogenic pressures can significantly alter the fire regime, increasing the frequency and intensity of forest fires, causing loss of natural habitats, soil degradation, and releasing large amounts of greenhouse gases into the atmosphere (Lovejoy and Nobre, 2018).

In this context, accurate mapping of areas affected by fire becomes an essential tool for monitoring and managing the impacts of forest fires in the Guianan savannas (Andela et al., 2022). It is important to note that changes in land use and vegetation cover, including burnt areas, can be identified through satellite-derived data, due to their distinct spectral response (Chuvieco et al., 2002). This allows for the characterization and differentiation of fire scars from other types of land cover. Spectral indices represent a simple approach for mapping fire scars, widely employed by various authors (Pereira et al., 2016). Thus, this study aimed to use spectral indices NBR, dNBR, NBRT, NDVI, SAVI, EVI, BAIS2, and MIRBI generated from Sentinel-2 satellite images to characterize the occurrence of fire scars in the Lavrado, in Roraima.

2. Materials and Methods

The study area corresponds to a part of the Guianan Savannas ecoregion, locally known as "Lavrado," located in the northeastern region of the state of Roraima. In addition to the predominant herbaceous cover, other types of vegetation formations can be found, such as small forest islands, gallery forests, and buriti palm groves that follow watercourses (Barbosa et al., 2005). The predominant climate in this region has two distinct seasons, one rainy and one dry. Average temperatures range from highs of 30°C to lows of 22°C, with an average relative humidity of 67%. During the period from October to March, the dry season occurs, with an average annual precipitation of 44.98 mm. The months with the lowest precipitation are January and February, with an annual average of 29 mm (Morais et al., 2015).

As a study area, a fire that began on August 30, 2017, and was controlled on September 3 of the same year was selected. From that date, the spectral indices presented in Table 1 were calculated using the Google Earth Engine. Subsequently, the images were classified into three classes (water bodies; unburned areas, and burned areas) in the QGIS application.

3. Results and Discussions

While some indices present relevant values for identifying the burn scars, the most suitable thresholds for this identification in the studied area are available in Table 1.

Spectral Indices	Reference Values		
	Water Bodies	Unburned Areas	Burned Areas
NBRT	-0,67 to 0,29	0,29 to 0,56	0,56 to 0,94
MIRBI	0,44 to 0,82	0,82 to 1,39	1,39 to 2,25
dNBR	-1 to -0,1	-0,1 to 0,2	0,3 to 0,9
EVI	-0,57 to 0,97	0,97 to 1,68	1,68 to 2,51

Table 1. Spectral index values for the 3 classes.

The EVI and dNBR indices demonstrated the ability to distinguish three major classes: water bodies, unburned areas, and burned areas. For EVI, spectral values ranged from 1.68 to 2.51 for identifying fire-affected areas, while for dNBR, they ranged from 0.3 to 0.9. Regarding MIRBI, spectral values ranged from 0 to 2.25, with burned areas corresponding to values from 1.43 to 2.25.

Notably, EVI and dNBR successfully identified both burned and unburned areas. However, MIRBI showed limitations by merging burned areas with water bodies, unable to distinguish between the two types of coverage. This inconsistency compromises the index's accuracy in identifying burn scars. NBR and NBRT were also able to differentiate two main classes: unburned areas and burned areas. However, similar to MIRBI, these two indices also failed to adequately distinguish between burned areas and water bodies.

Burn scars resemble vegetation suppression behavior, exhibiting low reflectance across the optical and near-infrared range. NBR uses the near-infrared range, which is strongly absorbed by water content in vegetation or soils (Bar et al., 2020). Consequently, the index aggregated areas that were not burned, possibly due to the presence of dry vegetation or other exposed soil areas in the region. dNBR was highly sensitive in detecting fire scars, as it was able to observe variations without confusing other low reflectance areas with burned areas. EVI was efficient in detecting burn scars, showing intermediate low values, without confusion with other objects.

Considering the characteristics presented by the spectral indices evaluated in this study, choosing the most suitable one for detecting burn scars becomes challenging. Studies often assess the performance of these indices in ideal scenarios, such as forest fires during the dry summer season, without considering different environmental conditions. Spectral response can vary due to various factors, such as atmospheric conditions, satellite image characteristics, acquisition timing post-fire, as well as local conditions like soil type, vegetation phenological stage, and season (Smiraglia et al., 2020). This variety of influences highlights the complexity in identifying the most suitable index for each situation and underscores the importance of considering all variables involved in the analysis.

4. Final Remarks

The purpose of this study was to evaluate various spectral indices NBR, dNBR, NBRT, NDVI, SAVI, EVI, BAIS2, and MIRBI in relation to identifying burned areas in the Guianan Savannas ecoregion, located in the Brazilian Amazon, specifically in the Lavrado region, located in the state of Roraima. We used Sentinel-2 satellite images with a spatial resolution of 10 meters to calculate these indices. We observed that EVI and dNBR stood out as the most effective indices in identifying burned areas, managing to distinguish them from water bodies with greater precision, approaching reality more closely. The use of these indices, especially EVI and dNBR, based on Sentinel-2 images, proved to be effective in delineating fire scars, offering a viable alternative for studying this type of phenomenon.

Additionally, we believe that the inclusion of additional variables, such as hydrographic layers of the region, can significantly improve the results of the indices, eliminating confusion between water bodies and burned areas and making the method more robust and reliable.

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