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IMAGE PROCESSING TECHNIQUES FOR TRAINING PHOTO INTERPRETERS IN THE VISUAL ASSESSMENT OF WETLANDS, AND MARKS AND SCARS FROM SLASH-AND-BURN AGRICULTURE AND WILDFIRES

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Abstract

Wetlands are one of the most valuable ecosystems on the planet; however, they are subjected to severe human pressure (slash-and-burn agriculture) and natural processes such as wildfires. One example is the Pantanal Sul-mato-grossense. Wetland monitoring on a large scale is crucial, but it is also difficult. The Pantanal Sul-mato-grossense was characterized and monitored using images from the Sentinel-2 satellite. The objective was to evaluate enhancement and spectral banding techniques for identifying patterns on the surface of wetlands, as well as slash-and-burn agriculture and wildfires on the Pantanal Sul-mato-grossense edge. The research selected two sample areas subjected to spatial enhancement using the pixel resampling technique. SWIR2M(12)NIR(8)BLUE(2) is recommended as the best composition for visual interpretation of damp areas and scars and stains from slash-and-burn agriculture or wildfires. In terms of spatial and temporal monitoring actions in wet areas, visual interpretation is an agile resource for a first approach to the evaluation and decision-making process.

Keywords: Wetlands; Pantanal; geoprocessing.

TÉCNICAS DE PROCESSAMENTO DE IMAGENS PARA TREINAMENTO DE FOTOINTERPRETES NA AVALIAÇÃO VISUAL DE ÁREAS ÚMIDAS E DE MANCHAS E CICATRIZES DE QUEIMADAS OU INCÊNDIOS

Resumo

Áreas úmidas são um dos ecossistemas mais valiosos da Terra, que estão submetidas a forte pressão antrópica (queimadas) e processos naturais como os incêndios. O Pantanal Sul-mato-grossense é um exemplo. O monitoramento em larga escala de áreas úmidas é de grande importância, mas também desafiador. Utilizou-se acervo de imagens do satélite Sentinel-2 cena de 11 de setembro de 2018, para caracterização e monitoramento do Pantanal Sul-mato-grossense. O objetivo consistiu em avaliar técnicas de realce e de composição de bandas espectrais para a identificação de padrões na superfície de áreas úmidas e de queimadas e incêndios na borda do Pantanal Sul-mato-grossense. A pesquisa selecionou duas áreas amostrais submetidas ao processo de realce espacial utilizando a técnica de reamostragem por pixels. Recomenda-se a composição SWIR 2M(12)NIR(8)BLUE(2) como a mais adequada para interpretação visual de áreas úmidas e de cicatrizes e manchas de queimadas ou incêndios. A interpretação visual é um recurso ágil para uma primeira aproximação no processo de avaliação e tomada de decisão em termos de ações de monitoramento espacial e temporal em áreas úmidas.

Palavras-chave: Áreas alagáveis; Pantanal; geoprocessamento

TECNICAS DE PROCESAMIENTO DE IMÁGENES PARA ENTRENAMIENTOS DE FOTOINTERPRETACIÓN EN LA EVALUACIÓN VISUAL DE AREAS HÚMEDAS Y DE MANCHAS Y DE CICATRICES DE QUEMADURAS O INCENDIOS

Resumen

Las zonas húmedas son uno de los ecosistemas más valiosos de la Tierra, que están sujetos a una fuerte presión humana (quemadas) y a procesos naturales como los incendios. El Pantanal Sul-mato-grossense es un ejemplo. El monitoreo a gran escala de las zonas húmedas es de gran importancia, pero también desafiante. Se utilizó una colección de imágenes del satélite Sentinel-2 para caracterizar y monitorear el Pantanal Sul-mato-grossense. El objetivo fue evaluar técnicas de realce y bandas espectrales para la identificación de patrones en la superficie de zonas húmedas y del quemadas y incendios en el borde del Pantanal Sul-mato-grossense. La investigación seleccionó dos áreas de muestra sometidas al proceso de mejora espacial utilizando la técnica de remuestreo de píxeles. La composición SWIR2M(12)NIR(8)BLUE(2) se recomienda como la más adecuada para la interpretación visual de zonas húmedas y cicatrices y manchas de quemadas o incendios. La interpretación visual es un recurso ágil para una primera aproximación al proceso de evaluación y toma de decisiones en términos de acciones de monitoreo espacial y temporal en zonas húmedas.

Palabras-clave: Zonas húmedas; Pantanal; geoprocesamiento.

1. INTRODUCTION

Wetlands are considered one of the most valuable ecosystems on the planet due to their ecosystem functions, with a focus on the preservation of water sources (Slagter et al., 2020). Their roles provide critical support for at least seven of the United Nations' 17 key sustainable development goals (RAMSAR CONVENTION, 2016). Depending on the type of wetland, some of its important characteristics include water storage and purification, coastal protection, carbon and nutrient processing, food security, and support for a diverse range of plant and animal species (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005; RAMSAR CONVENTION, 2016).

Nowadays, wetlands are disappearing faster than any other ecosystem, owing primarily to human activity (MILLENNIUM ECOSYSTEM ASSESSMENT, 2005). Hence, large-scale monitoring and characterization of various types of wetlands is critical for avoiding further losses and implementing and evaluating conservation policies (Slagter et al., 2020).

Surface water contains both organic and inorganic materials in its composition, and these materials have a strong influence on its spectral response (Sausen, 2007). When pure, the highest intensity of reflectance of electromagnetic energy corresponds to the visible spectrum (VIS). The reflectance peak shifts towards the longest wavelengths as the amount of sediments in the water body increases, approaching the spectral response of the soil, with a high reflectance rate in the far-infrared region (SWIR 2).

Wet areas with no free water depth have spectral values similar to wildfire areas and locations with dry pasture and undergrowth vegetation due to drought, with a height of more than 40 cm (Guo et al., 2017; Paranhos Filho et al. al., 2006). Optical sensors embedded in satellites, such as Sentinel-2 (ESA, 2019), with varying spectral resolutions between the VIS, VNIR (visible and near-infrared region), and SWIR 2 regions, enable the generation of images with bands modified to generate false-color compositions, emphasizing a greater reflectance difference between targets. This is a strategic manner of detecting specific targets in wetlands.

Enhancement is one of the digital processing steps, which, using subjective human eye criteria, aims to improve image quality by assisting the photo interpreter in discriminating the targets (INPE, 2019). Enhancement techniques use mathematical functions to modify the gray levels or digital values of an image. It is a well-known and widely used resampling procedure in Landsat (USGS) scenes, but it has received little attention in Sentinel scenes. Photointerpretation is the most agile image analysis technique, employing enhancement by generating colored compositions to produce quick and efficient results (Silva et al., 2021).

Thus, we sought to evaluate the enhancement of bands derived from the Sentinel 2 satellite, as a support for identifying patterns on the surface of wetlands, wildfires and slash-and-burn agriculture in the Pantanal Sul-mato-grossense.

2. METODOLOGY

The two areas selected for this study (Figure 1) are located in the municipality of Rio Verde, Mato Grosso do Sul, and contain land areas subjected to different flood pulses, which affect soil moisture and plant phenology. They also cover wetlands with Cerrado and Pantanal characteristics.

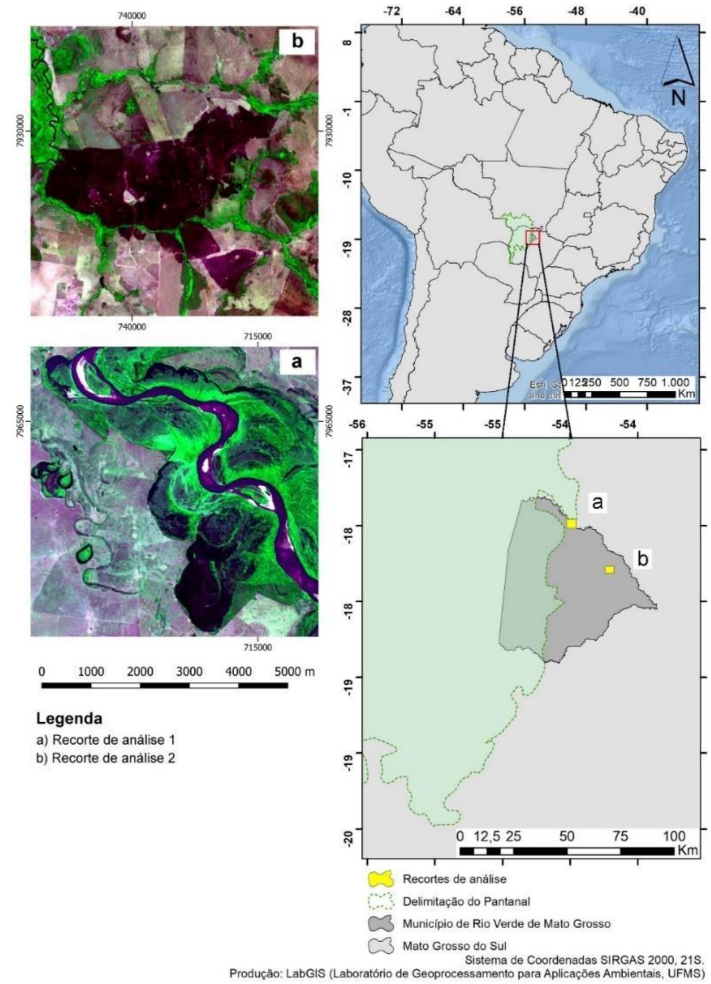

Figure 1 - Location of the two analysis areas on the edge of the Pantanal Sul-mato-grossense.

A scene from the Sentinel-2 medium resolution satellite (USGS, 2018) from September 11, 2018, was used, which is available in the public domain Earth Explorer USGS database (2018). The satellite was launched in June 2015 and has a multispectral instrument (MSI) that acquires 13 spectral bands, four with a spatial resolution of 10 m, six with a resolution of 20 m, and three with a resolution of 60 m. (Figure two). Its images supplement the USGS Landsat program, but with greater bandwidth and spatial resolution.

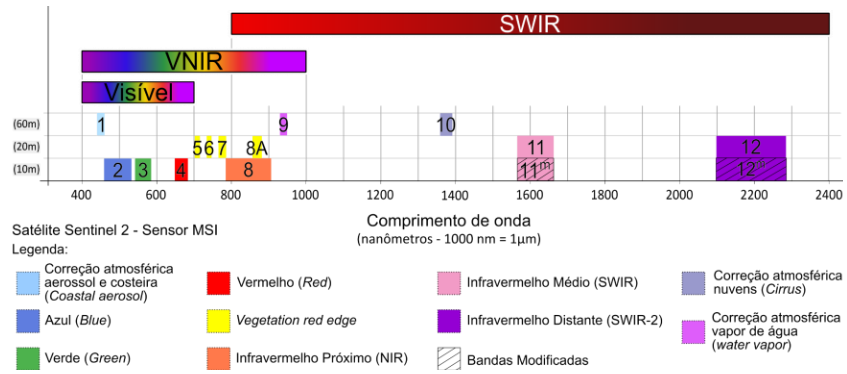

Figure 2 - Sentinel-2 Spectral Bands divided into VIS, VNIR and SWIR, with their respective spatial resolutions. The highlighted hatching represents the modified 11M and 12M bands that were created with the focus. The results can be found in Chapter 2. Source: Adapted from ESA (2019).

Following the download of the scene, image processing operations were carried out using the free software QGIS 2.18. (QGIS Development Team, 2017). Bands that were available in JP2 format were converted to geoTIFF. Resampling to 10 m was required due to the difference in spatial resolution between the VNIR (10 m) and SWIR and SWIR-2 (20 m) bands. The pixel resampling technique was used, which preserves digital level values without affecting statistical data (Figure 3). It is critical to note that this procedure does not improve spatial resolution, but rather matches the spatial resolution of the pixels.

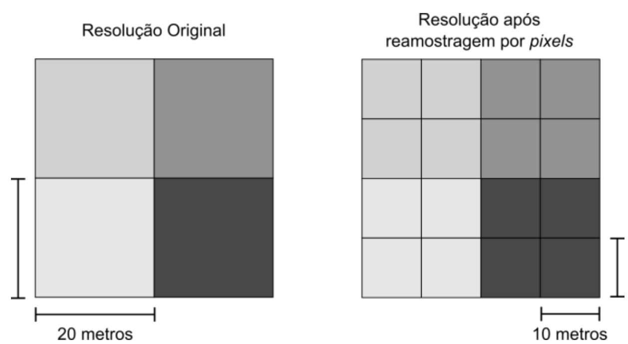

Figure 3 – Example of the spatial enhancement process using the pixel resampling technique.

After creating the SWIRM and SWIR 2M bands with a resolution of 10 m, an image with six spectral bands was generated (Red, Green, Blue, NIR, SWIRM and SWIR 2M). For analysis, six false-color compositions were chosen: one with VIS bands, one with VNIR bands, and the remaining four with resampled SWIRM and SWIR 2M bands. (See Fig. 4)

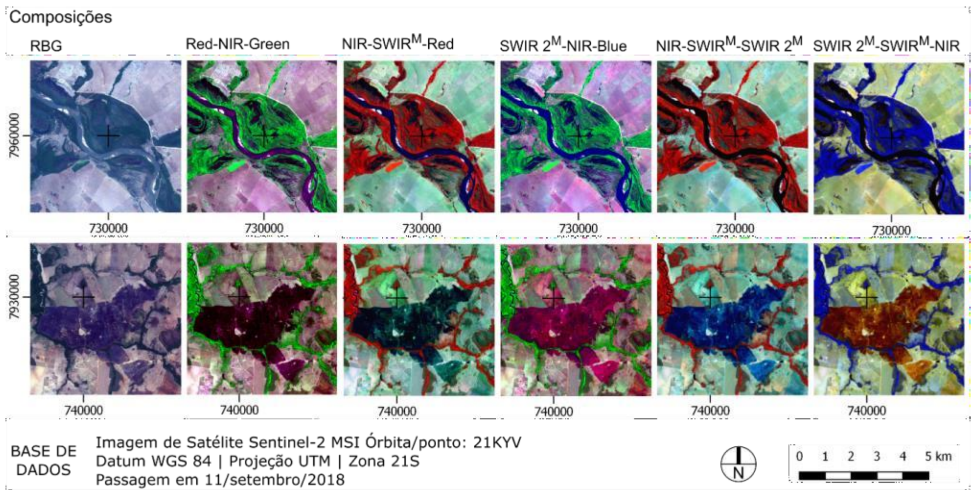

Figure 4 – Table containing the six false-color compositions with Sentinel-2 MSI bands that will be analyzed: R(4)G(3)B(2), Red(4)NIR(8)Green(3), NIR(8)SWIRM(11)Red(4), SWIR 2M(12)NIR(8)Blue(2), NIR(8)SWIRM(11)SWIR 2M(12) and SWIR2M(12)SWIRM(11)NIR(8).

The gray levels of the images were manipulated using the MinMax linear enhancement to improve the image analyst's visual acuity in identifying targets during the photointerpretation stage. The method consists of linearly redistributing the gray levels while maintaining their relative positions (INPE, 2019).

3. RESULTS

In the composition R(4)G(3)B(2) (true color), the water, vegetation and exposed soil have little variation in tones and colors, not allowing a distinction between the studied surfaces (Figure 5). Small waterways, as well as lakes present along the river's course, become imperceptible among the vegetation. Overall, the RGB composition, true color, has little variation in tones and colors, making it difficult to elucidate terrain classes, such as the different types of vegetation, which are better visualized in the false-color composition. Profile A features a large watercourse and vegetative mass surrounded by several sections of wetland, whereas profile B primarily consists of areas with wildfire or slash-and-burn agriculture marks, fire scars, and remnants of native arboreal vegetation

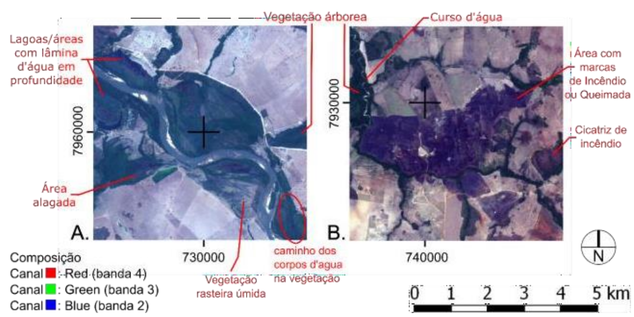

Figure 5 – R(4)G(3)B(2) composite (true color). All bands derive from the Sentinel-2 MSI VIS.

In profile B of Figure 5 there are fire marks that have a more bluish tone when compared to dark green areas with vegetation. Because of the low relative humidity and lack of rain at the time of image collection (September), slash-and-burn agriculture is common. Figure 6 depicts the locations of fire outbreaks that occurred at the same time as the image was captured (September 11^{th}). It is worth noting that the focuses are adequate in Analysis profile B.

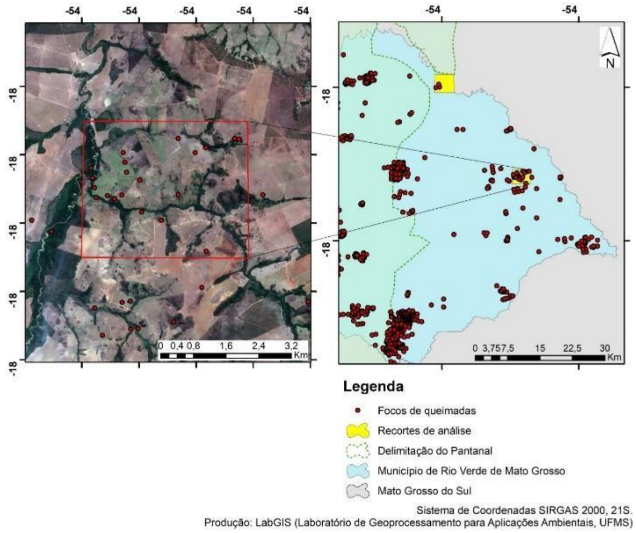

Figure 6 – Slash-and-burn agriculture outbreaks in analysis area B, showing that there were fires in this region for the same period. Source: http://queimadas.dgi.inpe.br/queimadas/bdqueimadas/

The RED(4) NIR(8) GREEN(3) composition is made up entirely of VNIR bands with a spatial resolution of 10 m. (Figure 7). This composition has a high reflectance of photosynthetically active masses and enhances vegetation with a green coloration (NIR in the green channel). Wetlands differ little from regions with exposed soil and fire marks (both purple in color), which are distinguished primarily by texture. In this composition, recent fire marks (purple hue) are easily distinguished from older fire scars (greenish hue with dark spots, Figure 7B), highlighting the region's initial growth of vegetation. The green channel's NIR band clearly highlights the vegetative masses in profile A. However, due to their low reflectance in the VIS bands, there is little differentiation between fire marks and wet areas in profile B.

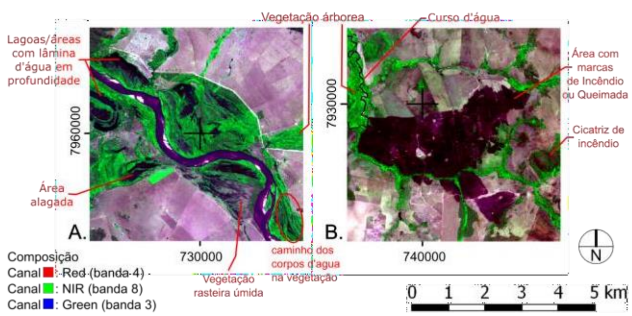

Figure 7 – RED(4) NIR(8) GREEN(3) composition with Sentinel 2 MSI VNIR bands.

Water (dark blue) and vegetation (red) presented good definitions for comparisons in the composition NIR(8) SWIRM(11) RED(4) (Figure 8), being properly differentiated from other elements of soil class. The water blades (moss green) in profile A are a different color than the clean water (blue); however, they are confused with fire marks in profile B.

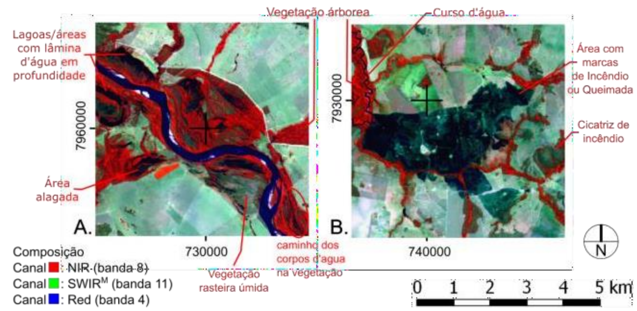

Figure 8 – NIR(8) SWIRM(11) RED(4) composition with modified Sentinel 2 MSI bands.

Because of the infrared spectrum, clean river water differs from water blades in depth because the reflectance peak moves in the direction of longer wavelengths as there is more sediment in the water. Nonetheless, areas with a deep water blade have a similar coloration (moss green) to fire marks and scars.

Wet areas (purple color) could be clearly distinguished from other features using the SWIR 2M(12) NIR(8) BLUE(2) composition (Figure 9A). As shown in Figure 9B, far-to-near infrared sensitivity helps distinguish the soil by separating it into a wider range of colors and separating the exposed soil (light pink color) from the fire marks (darker pink). Profile B presents a good distinction from soils with a wide range of colors, and they are significantly distinguished from fire marks. Wet areas in profile A have a purplish hue, while clear water has a bluish tone.

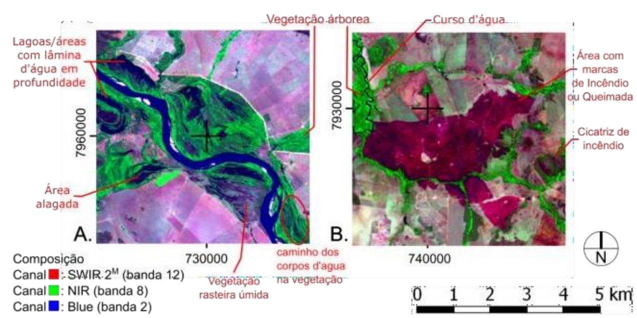

Figure 9 – SWIR 2M(12) NIR(8) BLUE(2) composition with modified Sentinel 2 MSI bands.

The SWIR 2M(12) SWIRM(11) NIR(8) composition (Figure 10) distinguishes wet areas (moss green) from areas with fire marks (orange color) the best. The composition highlights the vegetation in a darker blue shades compared to the previous SWIR 2M(12) NIR(8) BLUE(2), making small waterways difficult to identify, in addition to confusing clean water with water containing sediments.

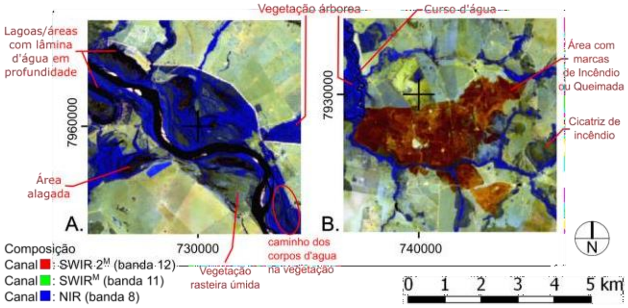

Figure 10 – SWIR 2M SWIRM-NIR composition with modified Sentinel 2 MSI bands.

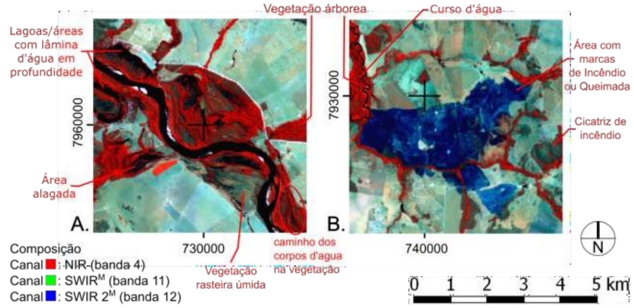

Figure 11 – NIR(8) SWIRM(11) SWIR 2M(12) composition with modified Sentinel 2 MSI bands.

The final composition NIR(8)SWIRM(11) SWIR 2M(12), which also has SWIR bands, shows the moist areas as a darker greenish color, which is significantly different from the color of the fire marks (in blue), but close to the color of fire scars (Figure 11). The vegetation is highlighted by the NIR band in the red channel.

For a better understanding of which sensors and band combinations produced the best results in the visual photointerpretation of flood pulses and wildfires, Table 1 compiles this information.

Table 1 - Synthetic chart of band combinations and their applications as well as of the best combinations in the visual identification of damp areas, marks of fire or burns, and scars from wildfires or slash-and-burn agriculture. Caption: AP = Appropriate; NP = Not Appropriate.

Composição	Alvos Detectáveis	Aplicação	Identificação de Áreas Úmidas	Identificação de Marcas de Incêndios ou Queimadas	Cicatrizes de Incêndios ou Queimadas
R(4)G(3)B(2)	Água, vegetação e solo possuem pouca variação de tonalidades. Pequenos caminhos d'água são imperceptíveis em meio à vegetação	Pouca aplicação	NP	NP	NP
RED(4) NIR(8) GREEN(3)	Identificação da vegetação fotossinteticamente ativa. Baixa diferenciação entre marcas de incêndio e áreas úmidas devido à baixa reflectância destas bandas	Aplicação no monitoramento de vegetação devido a banda NIR no canal verde dar ótima resposta à vegetação fotossinteticamente ativa	NP	NP	NP

NIR(8) SWIRM(11) RED(4)	Água e vegetação possuem boas definições de comparações. Água limpa do rio difere bem das lâminas d'água, porém as lâminas d'água confundem-se com marcas de incêndio	Boa combinação para classificação supervisionada, principalmente para as classes de vegetação, água, áreas úmidas, e solo exposto	AP	NP	NP
SWIR 2M(12) NIR(8) BLUE(2)	Diferencia bem as áreas úmidas, marcas de incêndios ou queimadas e cicatrizes de incêndio	Combinação apropriada para estudos de monitoramento de áreas úmidas, dimensionamento de danos de incêndios ou queimadas, e monitoramento da regeneração da vegetação das cicatrizes de incêndios ou queimadas	AP	AP	AP
SWIR 2M(12) SWIRM-NIR(11,8)	Áreas úmidas e marcas de incêndio ou queimadas. Confusão na identificação das classes de vegetação com caminhos d'água e entre áreas úmidas e cicatrizes de incêndios ou queimadas	Monitoramento das áreas em que houve queimadas ou incêndios; monitoramento de áreas úmidas	AP	AP	NP
NIR(8) SWIRM(11) SWIR 2M(12)	Boa diferenciação entre áreas úmidas e marcas de queimadas ou incêndios; Vegetação com boa diferenciação	Levantamento de fitomassa, área de vegetação fotossinteticamente ativa; monitoramento	AP	AP	NP

	e destaque devido a faixa NIR no canal vermelho	de queimadas e incêndios; monitoramento de áreas úmidas			

4. DISCUSSION

The spatial enhancement process enabled us to have a greater number of bands with comparable spatial resolution (10 m) available, increasing the possibilities for false-color composition and allowing us to differentiate more spectral targets. In theory, this process would result in a loss of spectral resolution. However, in practice, this loss was not significant in this study, allowing for a better identification of the spectral targets under study. It should be noted that because they are compositions with spectral bands originated from a relatively new satellite (launched in 2015), the advantages discovered may be due to the MSI multispectral sensor's response to electromagnetic radiation.

The compositions created with the modified SWIRM and SWIR2M bands identified targets that would have been impossible to identify with VNIR bands only. Wetlands showed little differentiation from regions with exposed soil and fire marks in compositions R(4)G(3)B(2) and R(4)N(8)G(3). So far, the study indicates that the SWIR 2M(12)NIR(8)BLUE(2) composition provides the best photo interpretative response of wetlands, presenting and clearly differentiating them from various soil covers.

Although several methods have been used for wetland mapping, the use of remote sensing data through satellite images is still difficult for fine-scale analysis, separating wetlands from other types of land cover without using additional data from field measurements, digital elevation models, LIDAR, and so on, due to the average spatial resolution of Landsat legacy, ASTER, or other satellites (Tiner et al., 2015; Kaplan & Avdan, 2018). Several studies have used the pixel resampling technique for enhancing orbital images to identify targets and support wetland monitoring using Sentinel-2 data with a spatial resolution of 10 m. (Wang et al., 2016; Kaplan, 2018; Wald, 2000). Even though all studies produced similar results, a recent comparison of the methodologies employed revealed that averaging the high-resolution bands to produce the missing panchromatic band produces the best results. The pixel resampling method provided quantitative and qualitative values that were close to ideal (Kaplan, 2018).

Because wetlands are difficult to distinguish from other similar covers, pixel resampling image enhancement using Sentinel-2 images has been used in soil cover and moisture mapping (Gao et al., 2017; Clerici et al., 2017). The use of the thermal band in conjunction with other spectrum bands makes it easier to distinguish between wet areas and locations with wildfire or slash-and-burn agriculture marks. The combination of the NIR and SWIR radiance ranges can provide more accurate differentiation of areas with marks and scars from wildfires and slash-and-burn agriculture from other elements, resulting in a most accurate distinction in the remaining subset. The process of classifying and combining electromagnetic bands classifies the landscape based on its variability; thus, if the within-class variance for a given band has been significantly reduced, it suggests that this band is fundamental for characterizing the class that is intended to be identified. The various combinations provide a set that indicates that the thermal band combination contributes to most of the variance across the entire subset of sampled areas; nevertheless, the classes of areas with wildfire or slash-and-burn agriculture marks show the thermal band as having the smallest standard deviations, highlighting the thermal band as a key factor for identifying these classes. Although the spectral band combinations studied here indicate which bands are important in interpreting wetland and burned areas classes, the overall combination of values between bands should ultimately determine the identification of these classes. For burned area classes, thermal emission values must be lower than those for other exposed area classes, even though they have lower SWIR values when compared to other surface types (Roy et al., 2019).

In the absence of true terrestrial data on the burned area, these spectral combinations increase classification confidence; that is, one can be more confident that the "highly likely" burned area classes are in fact burned and do not include other surface types/classes. However, the issue of underestimating the size of burned areas remains. This occurs when pixel values reflect a mix of cover types, either because only a portion of the area was burned, or because they are located in areas where previous fires occurred or where vegetation regrowth may already be present (Stroppiana et al., 2002; Li et al., 2000).

5. FINAL CONSIDERATIONS

After detailed analysis, the spectral band combination techniques used in this study provided important information on which are the best combinations in the identification of burned areas and wetlands. This was provided by a careful photo interpretative interpretation of the analyzed data. Because all Sentinel-2 imaging data is freely available, the techniques described here for identifying wetland and slash-and-burn agriculture elements, as well as wildfire scars and marks, can be applied to any other study area with characteristics other than those discussed here, as long as the spectral behavior of wildfire and wetland elements is similar. This research can be expanded across a larger area and over a longer period to create a more comprehensive database for fire ecology and wetland ecology surveys. The resulting data serve as the foundation for ongoing research into techniques for identifying and delineating wetlands, as well as spots and scars from wildfires and slash-and-burn agriculture, and, most importantly, digital monitoring of land cover dynamics.

Other researchers working with wetlands and burned areas within wetlands should find the modified bands spectral classification and combination approach useful. The method would benefit from further testing in other case studies, especially where real-time soil verification of burned and wetland areas is possible. A short-term series analysis that tracks vegetation regrowth after a fire in a single dry season would increase confidence in the interpretation of "potential" burned area classes and thus reduce the likelihood of omission errors.

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