

Fusion of Sentinel-1 and Sentinel-2 satellite images for detecting agricultural areas in Boa Vista do Tupim - BA

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Abstract

The aim of this study is to apply a decision-level spectral fusion technique to detect agricultural areas in the municipality of Boa Vista do Tupim - BA. The proposed approach is based on combining the probability maps generated from independent classifications of data acquired by the Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-2 Multispectral Imager (MSI) sensors to assess the performance of classifying seven land use and land cover (LULC) categories present in the study area. Methodology involves image selection and pre-processing, digital classification using the Random Forest algorithm, generation of probability maps, and evaluation of classification results using accuracy, precision and recall metrics. The results showed the potential for combining images from radar and optical sensors to detect LULC classes in Boa Vista do Tupim, BA.

Keywords: Remote sensing; Agriculture; SAR; Image fusion

1. Introduction

The municipality of Boa Vista do Tupim is located in the state of Bahia and in the Caatinga biome. The municipality is located in a geomorphological transition area between the Chapada Diamantina Plateau and the peripheral depression, with a gradient of elevation ranging from 300 meters in the areas of dense human occupation in the southeastern part to over 500 meters in the northwestern part. The typical climate is tropical savanna with dry winters (Aw) in the higher elevations and hot semi-arid at low elevations (Alvares et al., 2013). With more than 2500 farms, the main focus is on livestock production (Costa, 2024). According to IBGE (2023), the municipality is a major cattle producer with around 43,753 animals. However, low levels of rainfall aggravated by

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seasonal drought (Ab'Saber, 2003) and low natural soil fertility reduce agricultural productivity.

In the Northeast Region of Brazil, cloud cover is persistent, even in the least cloudy months (Silveira et al., 2017). In 2004, based on Sentinel-2 data analysis, more than 50% of the municipality of Boa Vista do Tupim was covered by clouds, almost always above 50%, which making the several remote sensing applications that require time series data unfeasible. Within this scenario, there is a need for alternatives to make remote sensing applications in the region viable. One possibility is the combination of different sensors to increase the amount of data, especially the ability of synthetic aperture radar (SAR) systems to obtain images regardless of cloud cover and solar illumination (Luchiari et al., 2011).

Several studies have linked agricultural productivity and management with the capabilities of remote sensors. In pasture management, Hott et al. (2024) compiled a series of academic papers with different approaches for pasture monitoring. Crabbe et al. (2020) found that the combination of Sentinel-1 and Sentinel-2 images enhance the ability to discriminate between different types of pasture, especially by using VH polarization.

One potential method is the fusion of optical and SAR images. Goyal and Wahlla (2015) described this method as the process of combining relevant data from different images into a single image, where the result is more comprehensive and valuable than its separate parts. Ghassemian (2016) reviewed the possible satellite fusion methodologies based on three aspects: pixel level, feature level, and decision level. This last method is described by Liu et al. (2018) as a process that combines the decisions or confidence levels generated individually by different sensors, based on a symbolic representation of the images. This approach operates at a higher stage of abstraction, where the results of independent classifications, such as probability maps, are integrated to form a joint decision, which can be binary (e.g. yes/no) or represented by a degree of confidence.

Wendl et al. (2018) proposed a Bayesian approach to data fusion at the decision level, where probability maps generated by different sensors are combined pixel by pixel using arithmetic operations. Bioresita et al. (2019) used this methodology to fuse time series from the Sentinel-1 and Sentinel-2 satellites to map permanent and temporary surface water in Ireland. This study seeks to analyze the fusion of Sentinel-1 SAR and

Sentinel-2 MSI images to detect agricultural areas in the municipality of Boa Vista do Tupim, BA.

2. Methods

The analysis relied on images acquired on 11 August 2022 from the European Space Agency (ESA) C-band, Sentinel-1 SAR and Sentinel-2 MSI data made available in L2A mode (atmospherically corrected). The blue (B2), green (B3), red (B4), and near-infrared (B8) bands of Sentinel-2 were selected, as well as the Normalized Difference Vegetation Index (NDVI) derived from the B8 and B4 bands. The bands were processed and stacked using QGIS 3.34 software. For Sentinel-1 satellite, we selected the images acquired on interferometric wide (IW), descending mode, and in the VH and VV polarizations, as well as the coherence matrix decomposition metrics (alpha, entropy, and anisotropy), extracted using SNAP 11.0 software and integrated into QGIS software.

Samples were manually collected, totaling about 2000 georeferenced points classified into seven thematic classes: forest, savanna, crop/pasture, urban, water, clouds, and shadows. These samples were used to train and validate models based on the Random Forest (RF) algorithm. For the model trained with Sentinel-1 data, the cloud and shadow classes were excluded as they did not show significant contrast in the radar response, resulting in a subset of 1500 samples.

3. Results and Discussion

The RF model, with a 70–30 split and trained with Sentinel-2 data, performed satisfactorily, with an overall accuracy of 95%. The crop/pasture class, of most important LUL class in this study, obtained a precision of 85% and recall of 95%, indicating a balanced performance in detecting this class. The water, shadow, and cloud discrimination presented superior performance, demonstrating the effectiveness of optical data in distinguishing targets with well-defined spectral signatures. In contrast, the model trained with Sentinel-1 data showed an overall accuracy of 65.8%, with lower performance in discriminating forest, urban, and savanna classes. The agriculture class showed reasonable performance, with precision of 65% and recall of 71%, which shows a complementary potential in detecting agricultural areas, especially in cloud cover conditions. Based on the training results, probability maps for the agriculture class were generated from the classifications considering the two sensors. The probability maps

were fused using two different approaches: the product of probabilities and the sum of normalized probabilities.

The fusion approach based on the product of probabilities resulted in an overall accuracy of 90.2% and recall of 62% for the crop/pasture class, indicating that, despite the high precision, there was an underestimation of the occurrence of the class of interest. This behavior can be explained by the specificity of the product operation, which heavily penalizes cases in which only one of the sensors has high confidence in the prediction. The method based on the sum of probabilities showed superior results. In this case, overall accuracy was 98%, with precision of 97% and recall of 97% for the crop/pasture class (Figure 1).

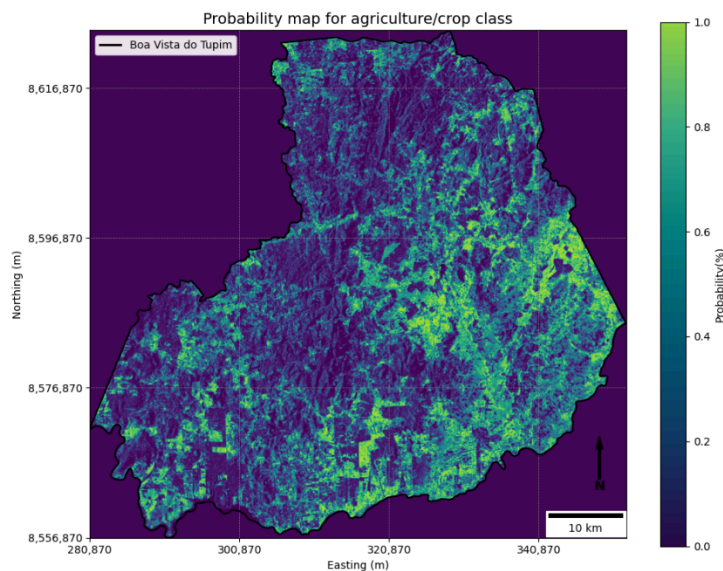


Figure 1 - Probability map of agriculture in Boa Vista do Tupim - Bahia.

The use of one or another method is expected to vary according to the specific nature of each data. Scenarios with a high risk of false positives benefit better from a more conservative estimation model. When the objective involves mapping more varying targets between sensors, the probability sum method becomes more relevant.

The results agree with those found by Wendl et al. (2018) who used decision-level fusion between SPOT-6 and Sentinel 1 for binary classification of urban areas. They found an accuracy of 90% with applying RF technique. A similar accuracy was found by Valero et

al. (2021) in mapping croplands in Europe using Sentinel-1 and Sentinel-2 images. Using the same satellites, Crabbe et al. (2020) found accuracy of 0.95 when the two images were combined to separate pasture types between one, two, or multiple species in Australia.

4. Conclusions

This study demonstrated the possible applications of spectral fusion for classifying agricultural areas in Boa Vista do Tupim - BA. By combining Sentinel-1 and Sentinel-2 images, we were able to exploit the potential of image fusion techniques to improve accuracy, especially in areas that are difficult to monitor due to persistent cloud cover conditions.

Despite the positive results, some specific points should be reported. Manual sampling tends to be limited in generalizing predictive models. A possible point for future study involves the use of already developed thematic mappings to expand sampling, such as those from the MapBiomass project. It is also beneficial to explore different prediction models and fusion methods, which may present more robust and generalized results.

Projects that need a constant flow of data, vital for precision agriculture and environmental management, can benefit from this work. Radar images have great potential for imaging critical regions that need constant monitoring, regardless of cloud conditions.

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