Identifying and Mapping Rice Crops in Flooding Area in the Vietnamese Mekong Delta based on Temporal Pattern using Sentinel-1 Time Series Data

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ABSTRACT

Monitoring rice cropping patterns is crucial for global food security and addressing environmental concerns related to water use and climate changes. Compared with conventional survey methods, remote sensing techniques prove to be time- and labor-efficient, particularly for large-scale and long-term rice mapping and monitoring. While both optical and Synthetic Aperture Radar (SAR) data have been extensively utilized for rice field mapping, optical observations are often limited during severe weather conditions, especially in tropical and subtropical regions. In contrast, SAR can penetrate the cloud cover and reflect the electromagnetic and structural properties of ground targets, so it is more suited for the continuous monitoring and mapping of rice cultivation in cloudy regions (Xu et al., 2023). Previous research affirms the efficacy of SAR time series in capturing crucial signals during key rice growth stages, offering a valuable tool for mapping in regions prone to cloud cover (Xu et al., 2018; Minh et al., 2019).

The Vietnamese Mekong Delta (VMD) is a critical region for rice cultivation, playing a central role in upholding the nation's food security. Located in the southern part of Vietnam, this expansive delta is featured by its fertile alluvial soils and an intricate network of waterways nourished by the Mekong River. The favorable climatic conditions and fertile land establishes the VMD as a cornerstone of agricultural productivity, particularly for rice production. In order to further intensify rice production, historical initiatives encouraged local farmers to shift to triple rice systems on fields shielded by high dikes, allowing for three harvests within a year. As a result, high dikes and flood control have become a distinctive feature across the upper floodplains of the VMD.

However, large-scale construction of high dikes has led to numerous adverse effects to local communities and ecosystems (Tran et al., 2018). On a regional scale, high dikes have reduced the water retention capacity of the floodplains, consequently amplifying flood risk in downstream, diminishing flows during the dry season, and exacerbating saltwater intrusion into freshwater areas. The isolation between the floodplain and rivers interrupted natural hydrological processes and ecosystem functions and negatively affected biodiversity. Farm profits are therefore expected to decline over time in the most intensive triple-rice cropping fields. Therefore, recent agricultural policies have shifted toward discouraging high dike expansion and promoting the restoration floodplain connectivity for more sustainable agricultural systems.

The objective of this study is to classify crop fields in An Giang province, located in upper floodplain of VMD, using Sentinel-1 image time series. Most studies require prior knowledge of rice phenology to define a time window for extracting phenology-related features, which restricts the applicability of these methods in regions without prior knowledge (Xu et al., 2023). This study employed yearly time series of Sentinel-1 backscatter values that incorporates the complete annual phenology cycle of rice growth to overcome the limitations of existing studies. Due to the variation in timing of crop transplanting, growing, and water inundation, farmlands with different cropping practices often present unique temporal patterns of radar backscatter. The temporal patterns serve as signatures to discern different cropping systems.

Identification of cropping types was implemented on a field basis. The field-based classification approach is often preferred for identifying rice paddy fields from SAR images due to its capabilities to mitigate the effect of speckles in SAR images and improve mapping accuracy (Xu et al., 2023). The overall landscape was first segmented using cloud-free Sentinel-2 composites during the dry season with clear boundary information using the CEWS workflow (Watkins and Van Niekerk, 2019). Pixels within each field segment were aggregated together to generate an average backscatter time series that represent the temporal backscatter patterns across the entire field.

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Subsequently, t-distributed Stochastic Neighbor Embedding (t-SNE; Maaten and Hinton 2008), a state-of-the-art embedding technique, was applied to project the time series into a 2-dimensional map to facilitate cluster analysis. Samples sharing analogous temporal patterns tend to stay clustered on the t-SNE 2D map. Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN; McInnes et al, 2017) was employed to identify the predominant temporal patterns within the dataset (Figure 1). The average time series of the clusters served as a reference temporal profile that characterized major land-use practices in the overall study area. The reference temporal profile associated to triple- and double-rice systems were identified based on field-labeled samples collected by the International Union for Conservation of Nature (IUCN).

Dynamic Time Warping (DTW; Salvador and Chan 2007) was employed as the metric to quantify the similarity between field time series and the reference profiles corresponding to triple and double rice systems observed based on field survey (Figure 2). A feature of DTW is its tolerance to time lag when comparing time series and thereby well accommodate the inter-annual variability of temporal patterns and disparity in flood inundation timing between upper and lower floodplains. Similarity-based classification was conducted, and fields were assigned to agriculture systems with the most similar temporal patterns if the DTW score is under a pre-defined threshold. Given the study's focus on rice paddies, fields with low temporal variations, typically referring to land practices with weak seasonality like buildup areas, perennial trees, orchards, and permeant water bodies, were omitted from the analysis. This classification method was implemented for two years, 2019 and 2022, in order to facilitate an assessment of changes in the area of triple rice cultivation in An Giang Province (Figure 3). The validation process relied on numerous labeled samples, with a particular emphasis on double-rice and triple-rice samples, given their prevalence in the IUCN-labeled dataset. The classification outcomes exhibited a notable concordance with IUCN field investigations, attaining an overall accuracy of >85% for the year 2022. The study provides important information and replicable methods for monitoring the implementation of policy changes in the Mekong Delta designed to restore floodplain connectivity and improve environmental and socio-economic resilience of the agricultural system.

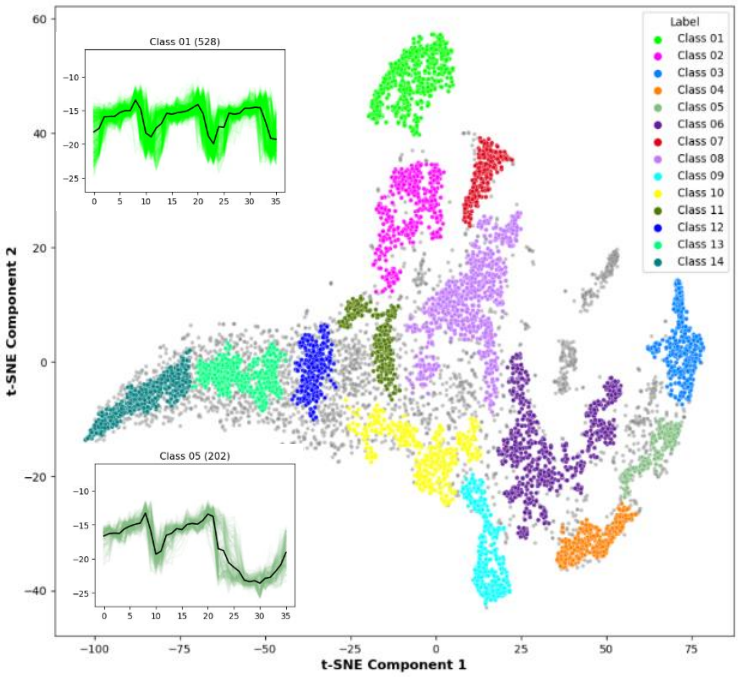

Figure 1. t-SNE map and HDBCAN clusters. Cluster 1 and 5 were identify as triple- and double-rice based on IUCN field investigation.

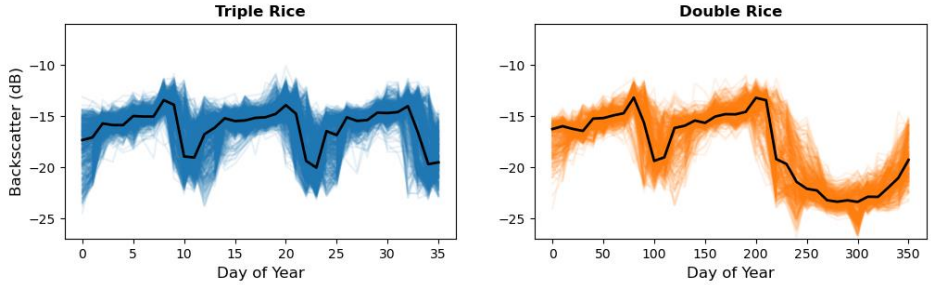

Figure 2 Reference time series (in black) for triple- and double-rice and the analogous crop field time series selected based on DTW scores.

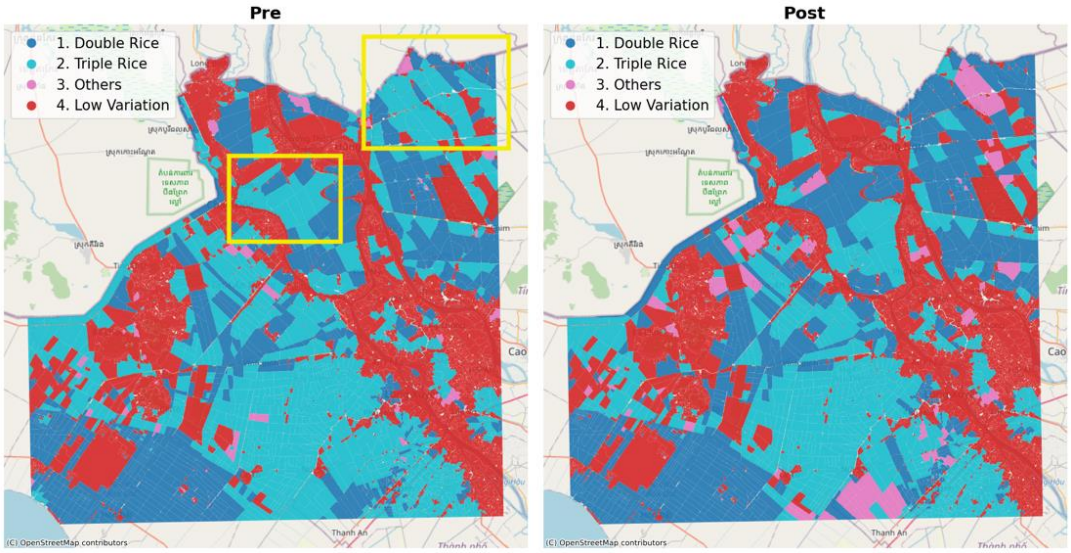

Figure 3. Crop field classification based on temporal backscatter patterns in An Giang province, Vietnam for Pre: 2019 and Post: 2022.

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