Sentinel-1 time series data analysis for identifying first water intake in paddy fields: A case study of the Subak system, Tungkub Irrigation Area, Bali

Sentinel-1 時系列データ分析による水田取水開始の把握：バリのトゥンクップ灌漑地区におけるスバックシステム事例

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1. Introduction

Subak is a water user association for paddy cultivation grounded in socio-cultural practices. During the dry season, water distribution is done through a rotational method to ensure equitable allocation amongst Subaks. This rotation system results in varying planting schedules amongst Subaks within the same irrigation area. Determining when and which Subak first receives water is crucial, as mismatches with water availability can lead to water shortages and delay planting. Furthermore, the early stages of land preparation and transplanting require substantial water, and water availability fluctuates over time due to climate change. Therefore, to assess the current status of water usage, it is essential to know when the first water intake occurs in paddy fields. The first water intake serves as an indicator that a particular Subak has commenced land preparation.

Satellites equipped with synthetic aperture radar sensors (e.g., Sentinel-1) provide easy data acquisition to obtain geographical data, regardless of the weather, which suits tropical regions like Indonesia, where clouds are formed relatively fast. Sentinel-1 produces images with 3-6 days revisit time and 10 m of spatial resolution. Using Sentinel-1 time-series data allows for the thorough detection of the first water intake, which is then used to map the past water distribution in the paddy fields' irrigation area.

2. Study area and methods

The study area is the Tungkub irrigation area between Badung Regency and Tabanan Regency, Bali, Indonesia. The Tungkub irrigation area collects water from the Tungkub weir located in the Sungi River, with an area of 1,092 ha and consists of 6 Subaks. Farmers can cultivate rice 2 to 3 times per year. In addition to rice, they also grow secondary crops using a small plot of paddy fields. In terms of communication, the leader of each subak uses a social media platform to facilitate discussions among Subaks. Each Subak has one month for land preparation. Once the first Subak finishes, the neighboring Subak starts land preparation, and so forth. They also have good days to start land preparation, transplanting, and harvesting. Farmers tend to start transplanting after all farmers in a Subak finish land preparation. Typically, after land preparation is completed, they keep the land flooded until the transplanting day begins. These practices highlight the variability in planting schedules within this area.

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This study utilizes time series data (2018–2024) from both Sentinel-1A and 1B with VH polarization. The data were obtained from NASA's Earth Data platform and preprocessed using the Sentinel Application Platform (SNAP) software. Preprocessing steps included subset, apply orbit file, thermal noise removal, border noise removal, calibration, speckle filter, terrain correction, and decibel (dB) conversion. Subsequently, the images were sorted, and the time-series function was applied. The images afterward were analyzed using Euclidean distance K-means clustering to determine paddy fields in the study area. The first intake was detected by identifying the sharp decline of backscatter value in the time series data and validated with ground-truth data using a confusion matrix.

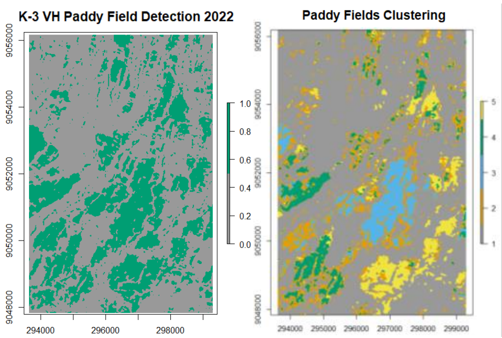

Fig. 1 The results of paddy field detection 2022 and paddy field clustering 2023

3. Ongoing results and discussions

K-means clustering performed well in detecting paddy fields in the Tungkub irrigation area. The elbow method was used to define the optimum numbers of clusters, and 3 clusters were the optimum for 2022 and 2023. Paddy fields in the 2022 image were successfully distinguished from other land cover types, with an overall accuracy of 77% and a Kappa coefficient of 0.52. The validation was conducted by comparing it with the Sentinel-2 Land Cover image of 2022 provided by ESRI. However, there is a drawback where some pond, river, grassland, and football court pixels were clustered as paddy fields. It may happen due to the low backscatter coefficient value of water bodies and the influence of rainfall on grassland and football courts, similar to paddy fields.

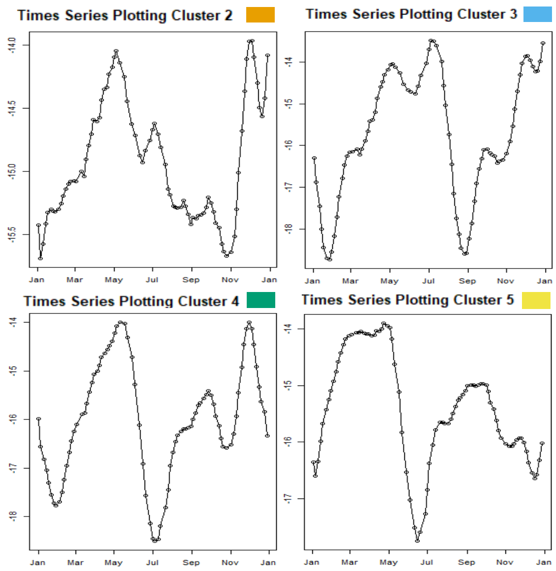

Fig. 2 Centroid value data of 2023 from clustering result

The paddy field maps were used to mask the initial images so that the paddy fields could be clustered to classify dissimilarity (planting schedule). The results showed that paddy fields with the same pattern or schedule can be grouped into one cluster (Fig. 1 & Fig. 2). Based on the comparison for 2023 between Subak's schedule with the centroid values of each cluster indicates an alignment between cluster results and the schedule (Fig. 3). In addition, rainfall data and optical satellite analysis is needed to gain the reliability of the results itself. The first water intake is currently underway.

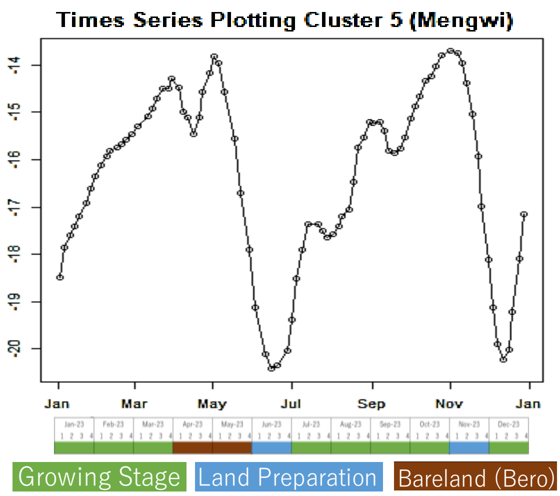

Fig. 3 Sample plotting on cluster 5 and planting schedule in 2023 for Subak Mengwi