Rice growth phase analysis in Pidie regency, Indonesia using multitemporal Sentinel-2 image data: a spectral angle mapper approach

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Abstract. Remote sensing data provides fast and relatively accurate information to retrieve the plant growth phase using spectral analysis. Spectral analysis of plants is the critical point of identifying the stages of rice growth using Sentinel-2 data. Sentinel-2 satellite images were utilized for this study. This study aims to analyze the growth phase of rice in Pidie regency, Aceh Province, Indonesia, as a sample area of the rice-growing site. The Spectral Angle Mapper (SAM) approach was performed to describe the plant growth stages. The results show variations in the rice growth phase across the study area for 2019, 2020, and 2021 growing seasons from vegetative, generative, wet fallow, and dry fallow. The most extensive vegetative phase is for April 2021 data, counting for 1,278.16 Ha. The most extensive generative phase was identified of June 2020 data, counting for 1,107.55 Ha. For wet fallow, counting for 949.30 Ha is the largest in this category. A total of 1,311.94 Ha of dry fallow is identified in 2019. The different growth phases and the total area for different years indicate variation in starting for the growing season of the sample location. In this paper, multitemporal Sentinel-2 data analyzed with the SAM approach has demonstrated identifying rice-growing season phases. This finding can help predict the total area along the year for a change of the pattern of the rice-growing season in the last three years of the study area.

1. Introduction

Rice (Oryza sativa sp.) is one of the most important cultivated plants in civilization, widespread and growing in almost all parts of the world. The rice plant is an essential rice-producing plant for the people of Indonesia because almost all Indonesian people consume rice as a staple food. Information about the condition of rice plants is necessary to estimate the growth phase and growing season by the control of production yields. The challenge facing Indonesia is a large number of land conversions from rice fields to other uses. Therefore, rice production in several areas shows a decreasing trend, including in Aceh Province [1].

Pidie Regency is one of the largest rice-producing regencies for Aceh province, with a planting area of 40,051.96 hectares and a total production of 248,059.62 tons [2]. The rice production in Pidie Regency for the last three years has decreased substantially. This condition may affect the rice growth phase.
production figures nationally. One of the efforts that can be made to obtain the cause of the national rice production not fully achieved as targeted is to monitor the growth conditions of rice plants. Thus, the local government could make policy adjustments in dealing with decreasing rice production as targeted. Remote sensing satellite data can be utilized to obtain information on rice growth in the last three years.

Remote sensing technology has provided fast and relatively accurate information for plant growth identification. Remote sensing information has become a complementary data supplier for monitoring networks in-situ. This information is accepted as a suitable option to contribute to sustainability in the land and water sector. In the context of agricultural monitoring applications, many environmental variables can be derived from various satellite platforms. These variables are related to agricultural land use, such as crop type discrimination, soil, and vegetation assessment, vegetation trend analysis, biomass, and yield mapping, or water use assessment. Several satellites have provided sensors with sensitivity and the ability to display vegetation spectral as a vegetation index and eliminate non-vegetated values [3]. One of the remote sensing satellite data that can be used is the Sentinel-2 satellite image. The Sentinel-2 satellite image is a medium resolution image released on June 23, 2015. This image can be used to assess land cover monitoring, including vegetation, soil, water, water networks, and coastal areas [4].

Identifying the growth phase of rice plants with satellite imagery can be done by looking at the reflectance value generated from image processing using one of the supervised classifications, namely the Spectral Angle Mapper (SAM) algorithm [5]. The SAM classification algorithm uses pixels in the image that has previously been atmospherically corrected and compares them with the reference spectral at the same n-dimensional [6]. The classification Spectral Angle Mapper method is a measure of similarity, not an identifier. Pixels classified into a particular class are not necessarily correct; they are more spectrally matched than endmembers. Therefore, analysis with other spectral tools is needed as an additional balance to define pixels to classes endmember [7]. By referring to the ability of spectral analysis using pixel-based in SAM, this study is utilized the multitemporal Sentinel-2 data to analyze rice plant growth with different SAM levels in Pidie Aceh, Indonesia.

2. Materials and methods

This research utilized a laptop equipped with ArcGIS 10.8, ENVI 5.3, QGIS 3.16.4, GPS, camera, sentinel-2 imagery for 2019, 2020, and 2021 acquisition, satellite imagery Bing Maps-Birds Eye Hybrid, Bing Maps Satellite, and Aragis Imagery. As a sample area of analysis, this study was carried out in three sub-districts; Mutiara Timur, Glumpang Baro, and Glumpang Tiga District (Figure 1). The method used in this study is a quantitative descriptive method and digital interpretation of satellite imagery Sentinel-2 with SAM algorithm. SAM is a physically-based spectral classification that uses an n-D angle to match pixels to reference spectra. SAM compares the angle between the endmember spectrum vector and each pixel vector in n-D space. Smaller angles represent closer matches to the reference spectrum.

Pre-analysis is a series of steps carried out to improve image quality. This stage is carried out before the analysis stage using ENVI 5.3 and QGIS 3.16.4 software. A radiometric correction was performed to the satellite data to correct the pixel values to reduce the atmospheric disturbance that may affect the image data quality and convert the digital radiance value to the reflectance value. This process was carried out using DOS 1 (Dark Object Subtraction 1) on the QGIS 3.16.4 software. Layer stacking was also performed to merge images from separate bands into one file. Determination of the research area is carried out by cutting satellite images according to the rice fields of the study area to make it easier to identify the rice-growing phase. The band combination was used is band 4,3,2, which displays the image's appearance with natural colors.

The analysis phase includes calculating days after planting rice plants, reflectance values, and classifying rice plants' growth phases using the SAM algorithm. SAM algorithm required an end member derived from the spectral reflectance of the target plant, which is carried out by measuring the similarity
between the spectral objects of an unknown entity and the reference spectral or called the spectral library every time. Rice growth phase and become a training area as a sample. Spectral Library is one of the parameters and inputs in the SAM classification process SAM. A spectral library is an information about the characteristics of the reflection or emission of electromagnetic waves from the spectral reflectance of each recorded object [8]. The spectral library, which has a higher number of channels, is assumed to classify with higher accuracy.

![Figure 1. Map of the study area.](image)

Classification of rice growth phase refers to the Balai Besar Penelitian Padi, A Center of Rice Research Board and the International Rice Research Institute, which state that the age of rice plants is expressed in planting days (PD). Based on the conditions in the field, the rice growth phase classes consist of wet fallow (-20 - 0 PD), vegetative (1 - 35 PD), generative (36 - 65 PD), and dry fallow (101 - 130 PD). The wet fallow phase is characterized by waterlogged soil that has not been planted with rice. Each phase of rice plant growth obtained from the classification results will be calculated its area [9]. The area calculation is based on the number of pixels in each class multiplied by the size of each pixel. These calculations show that the area changes in each phase of rice growth in the 2019-2021 range. An accuracy test was conducted to determine the level of accuracy of the classification results. Based on LAPAN's provisions, the accuracy for permitted land cover is above 75%. The results of the accuracy-test are the values of overall accuracy, and the kappa coefficient was also evaluated; even though this accuracy test is not yet commonly applied, this analysis rather than use radian angle use for SAM. However, in this study, the accuracy-test using the above approach is as an initial test.
3. Results and discussion

3.1. Distribution of phases and total area of rice

Based on the image processing results using the guided classification of SAM and ground checks in the field, we obtained four classes of rice plant growth phases with different distributions and areas of each phase. The
rice growth phase is divided into 4 phases: wet fallow, vegetative, generative, and dry fallow. The classification of rice growth phases based on the method SAM on five images can be seen in Table 1.

| No | Phases            | 2019 | 2020 | 2021 | 2020 | 2019 |
|----|------------------|------|------|------|------|------|
|    |                  | 19 Apr| 09 Mei | 08 June | 19 Apr | 20 Apr |
| 1  | Vegetative       | 1278.16 | 606.06 | 57.69 | 781.43 | 992.42 |
| 2  | Generative       | 488.63  | 807.93  | 1107.55 | 404.36 | 862.79 |
| 3  | Wet Fallow       | 140.80  | 949.30  | 793.81 | 44.70  | 265.00 |
| 4  | Dry Fallow       | 670.12  | 459.17  | 625.28 | 1250.74 | 1311.940 |
| 5  | Unclassified     | 6384.76 | 6118.23 | 6378.14 | 5912.88 | 9089.30 |
|    | Total            | 8962.47  | 8940.69  | 8962.47 | 8394.11 | 12521.50 |

Based on the classification results using the algorithm SAM of the April 19, 2021 image, the most significant phase area was obtained in the vegetative phase with an area of 1,278.16 Ha spread over all sub-districts of the study area. The size of the second-largest phase is in the dry fallow phase with an area of 670.12 Ha, which is spread dominantly in the Glumpang Baro District. The generative phase has an area of 488.63 Ha. The area of the lowest growth phase is the wet fallow phase, with an area of 140.80 Ha. The map of the rice growth phase distribution on the April 19, 2021 image acquisition can be seen in Figure 3.

On May 9, 2021, image data, the classification results have shown several points have undergone a phase change. The most significant phase area is in the wet fallow phase, with an area of 949.30 Ha. The second-largest phase is the generative phase, with an area of 807.93 Ha, which is spread dominantly in the Glumpang Baro District. The vegetative phase has an area of 606.06 Ha. The area of the lowest growth phase is found in the dry fallow phase with an area of 459.17 Ha and is dominant in Glumpang Baro and Mutiara Timur Districts. The map of the rice growth phase distribution on the acquisition of the image on May 9, 2021, is presented in Figure 4.

The rice growth classification on the image on June 8, 2021, shows the phase with the broadest distribution in the generative phase with an area of 1,107.55 Ha, which is spread dominantly in Glumpang Baro District. The phase with the second largest area is the wet fallow phase, with an area of 793.81 Ha, which is dominantly spread in Mutiara Timur District and Glumpang Tiga District. The dry fallow phase has 625.28 Ha, dominantly spread in Mutiara Timur District and Glumpang Baro District. At the same time, the area of the lowest phase is the vegetative phase with an area of 57.69 Ha and is dominantly spread in Glumpang Baro District. This shows that there is continuity starting from the acquisition in April 2021-June 2021. The map of the rice growth phase distribution in the image acquisition on June 8, 2021, can be seen in Figure 5.

The results of the classification of rice growth in the image of April 19, 2020, show the phase with the broadest distribution in the phase dry fallow with an area of 1,250.74 ha spread across all sub-districts of the research study area. The phase with the second largest area is the vegetative phase with an area of 781.43 Ha and is spread across all sub-districts of the research study area. In the generative phase, it has 404.36 Ha, which is spread dominantly in Glumpang Baro District. In contrast, the area of the lowest phase is the wet fallow phase, with an area of 44.7 Ha. The map of the rice growth phase distribution on the April 19, 2020 image acquisition can be seen in Figure 6.

The results of the classification of rice growth on the image of April 20, 2019, show the phase with the broadest distribution in the dry fallow phase with an area of 1,311.94 Ha spread in Mutiara Timur District. The phase with the second largest area is the vegetative phase, with an area of 992.42 Ha in all sub-districts of the research study area. In the generative phase, it has 862.79 Ha, which is spread dominantly in Glumpang Baro District. At the same time, the area of the lowest phase is the wet fallow phase, with an area of 265.00. The rice growth phase distribution map on the April 20, 2019 image acquisition is presented in Figure 3.
Each image has a different rice growth phase and is mutually sustainable. The dominance of the rice growth phase can be seen based on the calculation of the area of each phase which is presented in Table 1. The supremacy of the wet fallow phase is found in the image acquisition on May 9, 2021, with an
area of 949.3 Ha. In the image acquisition on April 19, 2021, the rice growth phase is dominant in the vegetative stage with an area of 1,278.16 Ha and a dry fallow phase of 670.12 Ha. In comparison, the dominance of the generative phase is found in the image acquisition on June 8, 2021, with an area of 1,107.55 Ha.

3.2. Accuracy Test

The classification of rice growth phases with the SAM algorithm shows the accuracy level obtained using the confusion matrix method. The accuracy test results are informed of overall accuracy values and kappa coefficient, shown in Table 2.

| No. | Image Acquisition   | Accuracy Value | Kappa Coefficient |
|-----|---------------------|----------------|-------------------|
| 1   | 19 April 2021       | 30.90%         | 0.17              |
| 2   | 09 May 2021         | 44.78%         | 0.28              |
| 3   | 08 June 2021        | 34.04%         | 0.16              |
| 4   | 19 April 2020       | 31.29%         | 0.14              |
| 5   | 20 April 2019       | 68.34%         | 0.51              |

The accuracy test results show that the accuracy of the SAM classification results in low classification accuracy results. Based on the provisions LAPAN, the average accuracy of the allowed land cover classification results is above 75%. The classification of rice growth phases using the SAM classification has classification accuracy results below 75%. The SAM classification calculates all bands in the image compared to other algorithm classifications, such as vegetation indices that only use less than three bands in the images analysis. The main advantage of the SAM algorithm is that it is a fast and easy method to map the spectral similarity from the image spectral to the reference spectral. It is also a powerful classification method because it suppresses the influence of the shadow effect to accentuate the reflectance characteristics of the target [9]. But this algorithm has the disadvantage that each pixel in the image is compared to the training area identified by the analyst and labeled as the most digitally similar class. Spectral Angle Mapper compares each pixel in the image with each endmember for each category and assigns a balancing value between 0 (low similarity) and 1 (high similarity). Endmembers can be taken directly from the image or characteristic spectra measured directly in the field or laboratory. The SAM algorithm does not consider sub-pixel values. The spectral mixture can be a problem because most of the earth's surface is heterogeneous. For medium resolution sensors such as Sentinel-2 imagery, wrong assumptions can be made and cause a low accuracy value [11].

A high classification accuracy value indicates a high level of classification accuracy and visual appearance accuracy, and vice versa. Classification results with an overall value accuracy below 75% can occur due to detecting the rice growth phase class not accurately see using other than vegetation indices[12]. The selection of the sample area may affect the classification process, resulting in a less than optimal classification. The accuracy value obtained is low. Errors in the pixel detection process in the image can occur due to the influence of digital images in recognizing each phase of rice growth [13]. The difference in image sharpness in identifying each phase of rice growth can cause a low level of accuracy. As in the vegetative and generative phases, both phases are still in the reproductive phase, with the dominant color being green, so the appearance of the two phases will be challenging to distinguish in the image—similar result with accuracy using SAM also obtained by[14]. Further results of alternative to monitor rice growth stage maps in the near-real-time with high accuracy of each rice growth stage models with cloud-free data using Sentinel 1 data was obtained by [15] with more dominant in the wet season (January February, and October–December).
4. Conclusion
The distribution of rice growth phases for images 2019, 2020, and 2021 has 4 phases: vegetative, generative, wet fallow, and dry fallow phases, spread in three districts, namely Mutiara Timur District Glumpang Baro and Glumpang Tiga. There are variations in the rice growth phase across the study area for 2019, 2020, and 2021 growing seasons: vegetative, generative, wet fallow, and dry fallow. The most extensive vegetative phase is for April 2021 data, counting for 1,278.16. The largest generative phase was identified in June 2020 data, counting for 1,107.55 hectares. For wet fallow, counting for 949.30 hectares is the largest in this category. A total area of 1,311.94 hectares of dry fallow is identified in 2019. The different growth phases and the entire area for different years indicate variation in starting for the growing season of the sample location. Compared to the vegetation index accuracy test of satellite image data, low accuracy results using SAM suggest that SAM does not treat individual bands in the algorithm rather than all bands in the image analysis. In this paper, multitemporal sentinel-2 data analyzed with the SAM approach can demonstrate the ability to identify rice-growing season phases. The main advantage of the SAM algorithm is that it is a fast and easy method to map the spectral similarity from the image spectral to the reference spectra.

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