ASSESSMENT OF THE EFFICIENCY OF USING MODIS MCD43A4 IN MAPPING OF RICE PLANTING CALENDAR IN THE MEKONG DELTA

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Abstract. This study used 487 MODIS MCD43A4 images, 1-day resolution, 500-meter spatial resolution to evaluate the efficiency of using the MODIS image series in monitoring the rice planting calendar in the Mekong Delta in 2019. The Savitzky-Golay filter method was applied to eliminate noise and smooth the time series of NDVI imagery. The rice planting date was then determined using TIMESAT software based on the threshold of increasing NDVI to 20% of the amplitude each season. The reliability of the model for mapping rice planting calendar was evaluated by compared to field data and local statistics. The results showed that the series of MODIS MCD43A4 images was used effectively in map of rice planting calendar for the Winter-Spring season, with area error was less than 10% and different of sowing date was less than 15 days (N = 21, MAE = 15 days, RMSE = 18 days). However, the series of MCD43A4 images was limited in monitoring the rice crop calendar of the other two remaining seasons (Summer-Autumn and Autumn-Winter) with an area error was greater than 30% and a higher difference in the time of sowing compared to the Winter-Spring season, especially in the Autumn-Winter season (N = 20, MAE = 22 days, RMSE = 23 days). The above results showed that the MODIS image series was effectively used in the dry season (Winter-Spring) and limited in the rainy season due to the influence of weather and clouds. Further studies combining the use of other types of satellite images or methods to replace cloud-affected pixels needed to be taken into consideration.

1. Introduction

Rice planting is the principal agricultural activity in most countries in South and Southeast Asia, and major source of employment and farmer’s income. Viet Nam was the world’s third biggest exporter and fifth largest producer of rice in year of 2015 (FAOSTAT, 2015). The Mekong Delta referred as “Viet Nam’s Rice Bowl”, is the biggest rice production areas in Viet Nam. More than 80% of the exported rice was produced from the Mekong River Delta (MRD), South Vietnam, which occupies more than 53% of the country’s rice land (V.N.Nguyen, M.H., N.A., & V.K., 2004). The statistical of the sowing timing of cultivated rice for each season is conducted after each season, mostly based on survey data and reports from localities. This work needs to spend a lot of time to investigate, synthesize data, and report for the whole region.
MODIS imagery with different temporal resolution are widely used in field of agriculture in the Mekong Delta. Specifically, analysis of agricultural transformation in the Mekong Delta using MOD09A1 8-day temporal resolution (Sakamoto, 2009), monitor the status of rice growing stage using MOD13Q1 16-day temporal resolution (Tran Thi Hien et al., 2013), change of rice crop calendar by MOD09Q1 8-day temporal resolution (Tran Thi Hien and Vo Quang Minh, 2014), effect of drought and flooding on rice crop calendar under the impacts of climate change using MOD09A1 and MOD11A2 8-day (Huynh Thi Thu Huong, 2017). The results of these studies show that the MODIS imagery has been effectively applied in monitoring and identifying fluctuations in local rice crop calendar using time series of MODIS NDVI. However, there are still limitation of the temporal resolution (8-day or 16-day) of the NDVI product from above studies. The result of interpreted sowing date could be high uncertainty if there are one or two period of images missing due to effect of cloudy. Currently, MODIS MCD43A4, a combination product between AQUA and TERRA sensors containing data with daily temporal resolution and 500 met spatial resolution, is a good product for monitoring the dynamic of land surface, allowing to detect the change of vegetation growth continuously. The effectiveness of this MCD43A4 product in monitoring the rice crop calendar in Mekong Delta whereas facing cloudy problem need to examined.

In addition, the previous research in this study areas using the supervised classification method to group pixels with the similar fluctuating pattern of NDVI time series for mapping the rice crop calendar which could not explain the vary of sowing date between pixels. The studies in comparing the different algorithms in extracting the start of season (SOS) and end of season (EOS) of the multi-time data series have shown that TIMESAT is an advance tool which can use for integrating filtering methods at suitable thresholds (Gholamnia et al., 2019; Stanimirova et al., 2019). TIMESAT is developed with the strength of processing multi-time data series of satellite images allowing to extract effective the seasonality parameters on the pixel level (Eklundh & Per, 2015). This study aims to evaluate the effectiveness of using the series of MODIS MCD43A4 in monitoring the rice crop calendar in the Mekong Delta through using TIMESAT software.

2. Study methods

2.1 Used Data

The MODIS MCD43A4 daily product with 500 m resolution (Table 1) cover Mekong Delta was freely collected at the NASA Land Processes Distributed Active Archive Center (LP DAAC). A total of 487 imagery were collected from September 01, 2018 to December 31, 2019. In particular, 122 imagery of the year 2018 (from September 1, 2018 to December 31, 2018) were collected to interpreted the sowing date of the Winter-Spring season in 2018-2019 and 365 imagery in 2019 (January 1, 2019 to December 31, 2019) were used to interpreted the sowing date of the Summer-Autumn and Autumn-Winter season in 2019.

MCD43A4 data includes information layers of surface reflection. This study used Band 1 (RED) and Band 2 (Near-infrared, NIR), described in Table 1:

| No       | Band name | Wavelength (µm)   | Resolution (m) | Scale factor |
|----------|-----------|-------------------|----------------|--------------|
| Band 1   | RED       | 0.620-0.670       | 500            | 0.0001       |
| Band 2   | NIR       | 0.841-0.876       | 500            | 0.0001       |

(Sources: https://lpdaac.usgs.gov/product)

The other maps were collected including the current land use map at the Mekong Delta to identify the distribution areas of rice cultivation, the administrative boundary map of the Mekong Delta provinces (Figure 1).
2.2 Methodology

This study used the MODIS MCD43A4 product daily with 500m spatial resolution, in combination with TIMESAT software to estimate the rice sowing date for each pixel based on the analyzing the changing of minimum and maximum values of the NDVI time series during period of study. The Savitzky-Golay method has been applied to eliminate noise and smooth the series of NDVI images (Chen et al., 2004; Zhang et al., 2017) which have not widely used in the previous research in the Mekong Delta yet. The prediction error method using the Mean Absolute Error (MAE) and the Root Mean Squared Error (RMSE) were applied for the accuracy assessment in this study (Wagle et al., 2014). Detail for each part of processing is described in the following:

2.2.1 Pre-processing images

The collected MODIS MCD43A4 data was adjusted standard coordinate system, WGS84 (World Geodetic System 1984), Zone 48N for the research area by using the MRT (Modis Re-Projection Tool), provided freely by NASA. The Mekong Delta is located on two different scenes, image mosaic and resize were performed to limit the research area and reduce the image size serving image processing in the next step.

2.2.2 Creating an image of Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is an index that estimates the coverage of vegetation by measuring the difference between the near-infrared band (reflected strongly by plant) and red band (absorbed by plant). The time series of NDVI imagery will be used to monitor changes in vegetation covering status and calculated using the following formula (Tucker, 1979):

\[
NDVI = \frac{(NIR - RED)}{(NIR + RED)} (-1 \leq NDVI \leq 1)
\]  

(1)
where:
- NIR is reflection in the near-infrared spectrum
- RED is reflection in the red range of the spectrum

### 2.2.3 Mapping of rice planting calendar and evaluate the variation

The NDVI value of each crop has certain range. The NDVI index of one rice crop season fluctuates follow the rule as lowest at the beginning of season (seeding and transplanting), gradually increasing and reach the peak at reproduction phase, and declining at the end of the season (ripening and harvesting phase) (Tran Thi Hien and Vo Quang Minh, 2014).

The calculated time series of NDVI imagery was used as input parameter in the TIMESAT software to process and analyze and create a map of rice planting date (start of season) (Jönsson and Eklundh, 2004). The Savitzky-Golay method has been applied to eliminate noise and smooth the series of NDVI images before calculating seasonality parameters; (Chen et al., 2004; Zhang et al., 2017). The time series of NDVI was selected from 2014-2018 to assess the growth cycle of rice in 5 years (drought year in 2016 and 4 remaining neutral years). Start of season (SOS) is defined based on the threshold of deviation of 20% from the amplitude of the minimum NDVI. According to Eklundha and Jönssonb, 2012 the formula is shown as follows:

\[
SOS = NDVI_{\text{min}} + (NDVI_{\text{max}} - NDVI_{\text{min}}) \times 0.2
\]  

(2)

In which, \(NDVI_{\text{min}}\) and \(NDVI_{\text{max}}\) are the minimum and maximum NDVI values during the cultivation period of each season. Algorithm (2) is applied to calculate sowing time for each pixel in the entire study area of Mekong Delta.

### 2.2.4 Evaluating the reliability

The study used field survey and statistics data to compare and evaluate the reliability of rice planting calendar map and effectiveness of MODIS data in this study.

- **Comparison of rice planting calendar extracted from MODIS to field survey data.**

The field survey was conducted to identify the actual rice planting date in 2019. Due to limit of time, the study chose Hau Giang province to conduct a field survey. The results were used to calculate forecast error as follow:

- **Prediction error**

  The prediction error is the difference between the observed and the predicted for a given period. Prediction errors also helped to adjust the parameters of the forecasting model (Wagle et al., 2014). This study used Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) to evaluating the reliability of rice planting calendar map.

  + **Mean Absolute Error (MAE):** MAE measures the average magnitude of the errors in a set of predictions, without considering their direction.

\[
MAE = \frac{1}{n} \sum_{i=1}^{n} |e_i| = \frac{1}{n} \sum_{i=1}^{n} |y_i - \hat{y}_i|
\]  

(3)

+ **Root Mean Squared Error (RMSE):** is the standard deviation of the residuals.

\[
RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} e_i^2} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2}
\]  

(4)

Where: \(n\) is the number of observation
YT: The observed value at t point  
ŶT: The predicted value at t point (in correspond with t observation)  
εt: Predict error at t point

❖ **Comparison of rice planting calendar extracted from MODIS to statistics data**

The difference of rice planting areas for each period extracted from time series of MODIS NDVI with rice planting data from the 2019 statistical yearbook was conducted evaluate the reliability of rice planting calendar map.

3. Results and discussion

3.1 NDVI time series for rice crop calendar

NDVI time series provides the information for monitoring changes in vegetation cover status over time. In the rice crop calendar, the pixel has the curve of NDVI value follows a sinusoidal pattern with two times reach maximum point (NDVI_{max}) corresponding to the pixel with double rice crop areas, and the curve with sinusoidal pattern with three time reaching the maximum points presented for triple rice crop areas. The variation rule of time series of NDVI values over time was determined for identifying the time of sowing of each season. The algorithm used on TIMESAT is based on formula (2) for sample pixels and was executed for all pixels for each season. The variation of NDVI time series and an example determining the sowing time for rice crop season was shown in Figure 2. The start of growing season (SOS) values were calculated for each pixel corresponding to the order of the images in the NDVI series of the input model, and then converted to date of year to compare with field survey data and statistics from the yearbook.

![Figure 2](image-url)  
**Figure 2.** The variation of NDVI values for double rice crop (left) and triple rice crop (right)

The illustration in Figure 2a showed the variation of NDVI values of a pixel of double rice crop (Summer-Autumn and Winter-Spring), whereas the SOS of Winter-Spring season was on October 25, 2018 (the 298th image in a series of 487 imagery), the SOS of Summer-Autumn season was on April 24, 2019 (114th image in a series of 487 imagery). Similarly, pixel of triple rice crop (Winter-Spring, Summer-Autumn, Autumn-Winter) showed in Figure 2b, the SOS of Winter-Spring season was on November 22, 2018 (322th image in a series of 487 imagery), SOS of Summer-Autumn was on April 10, 2019 (102th image in a series of 487 imagery) and SOS Autumn-Winter was on August 5, 2019 (217th image in a 487-series imagery). The SOS of remaining pixels of rice crop areas were calculated on TIMESAT using the same rule of sample pixels to map the rice planting calendar in the Mekong Delta in 2019.

3.2 Analyzing the rice planting calendar in the Mekong Delta

According to statistics Department, the Mekong Delta had about 4,107.4 thousand ha of total rice cultivation area in 2018 (General Statistics Office, 2018). Planting area of Winter-Spring season was 1,573.5 ha, total area of Summer-Autumn and Autumn-Winter were about 2,336.7 ha, distributed mainly
in Long An, Dong Thap, An Giang, Kien Giang, and Soc Trang provinces. Meanwhile, the total area of Winter rice (mono rice crop) is only 197.2 thousand ha, distributed scatter in coastal provinces such as Ca Mau, Kien Giang, Bac Lieu, Soc Trang. The distribution area of mono rice crop cultivation was quite small (only 4.8% of the total rice area of the whole region), therefore this study focused only on analyzing the planting rice calendar of double rice crop and triple rice crop areas in Mekong Delta.

3.2.1 Rice planting calendar of double rice crop areas

The double rice crop in Mekong Delta mainly consists of the Winter-Spring and Summer-Autumn seasons. However, in some areas the SOS of Winter-Spring season was earlier or Summer-Autumn season was later due to the local climate conditions and characteristics of farming. The rice planting calendar for each season of double rice crop areas in the Mekong Delta was shown below Figure 3.

![Figure 3](image-url)

**Figure 3.** The distribution of rice planting calendar of the double rice crop in the Mekong Delta in 2019

The rice planting calendar of Winter-Spring season started from October 25, 2018 to December 3, 2018 in which farmers sowed mainly during the period from November 14, 2018 to December 3, 2018 as Soc Trang provinces, (Nga Nam, My Tu district) Long An (Vinh Hung, Tan Hung, Moc Hoa district), Can Tho (Vinh Thanh district), Dong Thap (Tan Hong, Hong Ngu, Tam Nong, Thanh Binh district), Kien Giang (Kien Luong, Hon Dat, Giang Thanh district). The total area of rice planting in Winter-Spring season was about 676,850 ha.

The rice planting calendar of Summer-Autumn season started from April 24, 2019 to June 4, 2019 (Figure 3b), in which farmers in some provinces sowed mainly within 10 days from May 5, 2019 to May 15, 2019. The sowing time of some areas along the coastal provinces as Kien Giang province (Long Xuyen quadrangle region), Ca Mau (Tran Van Thoi district), Soc Trang (Tran De district) was 15-20 days later than common time. The time of sowing in the Summer-Autumn falls into the transition period between the rainy season and the dry season. According to the report of government, there was a high risk of saline intrusion during the dry season in 2019 in the Mekong Delta provinces, salinity intrusion occurred earlier with higher concentration in the dry season of 2019. Along with that, the distance of saline intrusion into the river was from 45-65 km in Ben Tre, Tra Vinh, Soc Trang, Bac Lieu, Hau Giang, Long An, Kien Giang, especially the saline intrusion in Vam Co River was over 70 kilometers (Ministry of Natural Resources and Environment, 2019). Therefore, the rice planting calendar was also affected by delaying sowing date to avoid the effects of saline intrusion in coastal provinces.

3.2.2 Rice planting calendar of triple rice crop areas
The triple rice crop in Mekong Delta mainly consists of Winter-Spring, Summer-Autumn, and Autumn-Winter. Triple rice crop is mainly located in areas with good irrigation systems, abundant fresh water and adequate water supply facilities. The rice planting calendar for each season of triple rice crop areas in the Mekong Delta was shown below Figure 4.

Figure 4. The distribution of rice planting calendar of the triple rice crop in the Mekong Delta in 2019

The sowing time of Winter-Spring season for triple rice crop area started from November 5, 2018 to December 15, 2018, with a total sowing area of 782,350 ha. The rice planting calendar of Winter-Spring was mainly occurred about 20 days in the end of November, mostly distributed in Can Tho (Co Do district), Vinh Long (Tam Binh, Tra On district) and Dong Thap (Lai Vung, Thap district) provinces. Ten), Tien Giang (Cai Be and Cai Lay district) and Soc Trang (Chau Thanh district). In some areas of An Giang, Tien Giang (Go Cong Tay district) and Tra Vinh provinces, the rice sowing date was about 15 days later than the common sowing time. In addition, there are some small areas sowing earlier in about 5 days, but the difference is not significant.

The rice sowing time of Summer-Autumn season started from March 20, 2019 and ended until April 29, 2019, mainly sowing in period of 30/3/2019 to 19/4/2019. The total cultivated rice area in Summer-Autumn season was about 436,125 ha.

The rice sowing time of Autumn-Winter season started from July 5, 2019 to August 14, 2019, with an estimated sowing area of about 411,175 ha. In this crop, the rice planting calendar also concentrated for
about 15 days starting from 01 August 2019 in the Vinh Long, Tra Vinh, An Giang, Tien Giang, Kien Giang and Soc Trang province. The sowing time of remaining areas were earlier than common time including Long An, Can Tho, Dong Thap, Kien Giang, Bac Lieu province with the sowing time scattered from July 5, 2019 to July 25, 2019.

3.3 Evaluating the effectiveness of using the series of MODIS MCD43A4 imagery in mapping rice planting calendar

3.3.1 Assessment of reliability using field surveys

In general, the rice planting calendar extracted from TIMESAT and the observed rice planting date from field survey in Hau Giang province in 2019 are not much different (Table 2):

Table 2. Comparison of rice planting calendar from TIMESAT with local's rice planting calendar

| Criteria          | Winter-Spring | Summer-Autumn | Autumn-Winter |
|-------------------|---------------|---------------|--------------|
| N                 | 21            | 10            | 20           |
| MAE (day)         | 15            | 13            | 22           |
| RMSE (day)        | 18            | 17            | 23           |

The prediction errors were also examined though MAE and RMSE using formulas (3) and (4). Results are also detailed in Table 3.

Table 3. The prediction errors of interpreted rice planting calendar using field data

Out of 44 actual survey points, there are 21 points used for evaluating the accuracy of the planting date in Winter-Spring season, 10 points used for the Summer-Autumn season, and 20 points used for the Autumn-Winter season. Table 5 showed that there are differences in the rice planting calendar using TIMESAT compared to the observed calendar. The average difference between the Winter-Spring season is about 15-18 days; the Summer-Autumn season is about 13-17 days and the Autumn-Winter season is 22-23 days. The differences between interpreted and observed rice planting calendar could be found due to the different definition of the rice planting calendar. The predicted calendar from TIMESAT was understood as the date when the lowest NDVI value increases by 20% compared to the maximum NDVI value at the beginning of each season, meaning that the rice has germinated and sowed about 10-15 days. Meanwhile, with the observed rice planting calendar, the farmers identified rice planting date is the sowing date. Therefore, in practice, the interpreted rice calendar extracted from NDVI time series using TIMESAT is used effectively in monitoring the rice planting calendar in the Mekong Delta.
3.3.2 The comparison to statistics data

The cultivated rice area for each stages recorded in the statistics report for the first nine months of 2019 (The Ministry of Agriculture and Rural Development, 2019) were compared to the total cultivated rice area extracted from the NDVI MODIS. Results are presented in Table 4.

Table 4. The comparison of the rice planting areas between statistics and interpretation in the Mekong Delta region (Unit: ha)

| Month | Winter-Spring | Summer-Autumn | Autumn-Winter | Difference (%) |
|-------|---------------|---------------|--------------|----------------|
|       | Statistics    | MODIS         | Statistics   | MODIS          |                |
| 1     | 1,573,100     | 1,442,850     |              |                | 8.28           |
| 2     | 1,601,692     | 1,451,750     |              |                | 9.35           |
| 3     | 1,604,273     | 1,459,200     |              |                | 9.04           |
| 4     | 702,180       | 663,475       |              |                | 5.51           |
| 5     | 1,064,656     | 982,625       | 1,535,968    | 1,070,900      | 30.28          |
| 6     | 1,562,628     | 1,086,725     |              |                | 30.46          |
| 7     | 315,646       | 93,350        |              |                | 70.42          |
| 8     | 403,510       | 210,100       |              |                | 47.93          |
|       | 664,451       | 411,175       |              |                | 38.12          |

The analysis of the difference of planting area between the interpretation and the statistics record showed that the difference was estimated to not exceed 10% in the Winter-Spring season (Table 4). However, the different percentage in the Summer-Autumn and Autumn-Winter season was quite high. The reason is that the NDVI time series was calculated from MODIS MCD43A4 which was affected by clouds in the period from the end of the Summer-Autumn to the Autumn-Winter season, the image of 56th (June 5, 2019) to 233th (August 21, 2019) of total 487 images. During this period, a pixel value of NDVI was low and NDVI time series did not show SIN curved as common pattern. In case the time series of imagery does not meet the conditions of analysis according to the rule of increasing and decreasing NDVI values at the sample pixels, the TIMESAT processing will eliminate the execution for those pixel locations. The only pixels with pattern of time series NDVI following rule of sample pixels are used to calculate and execute for rice planting calendar results. Therefore, the total area for sowing in the Summer-Autumn and Autumn-Winter season was lower than the recorded statistics.

In general, the evaluation results reveal the effectiveness of using the MODIS MCD43A4 time series in mapping of rice planting calendar the Winter-Spring, with areas error of prediction of less than 10% on the total planting area and the difference in planting date was in line with reality. Meanwhile, the series of MODIS MCD43A4 are limited when using the calculation of rice planting calendar for the Summer-Autumn and Autumn-Winter season of the triple rice crop. The reason is due to the influence of clouds during the rainy season, leading to the loss of data values, disrupting the continuity of NDVI time series when analyzing the rice growth rule.

In generally, the time series of NDVI MODIS MCD43A4, a daily with 500-meter resolution has a capability to track the rice planting calendar in the Mekong Delta in 2019. Regarding the double rice crop, the Winter-Spring season was started on between October 25, 2018 and November 24, 2018, with the planting area of about 676,850 ha; the Summer-Autumn season started planting from April 24, 2019 to June 4, 2019, with an area of about 650,600 ha. The planting time of coastal provinces of Ca Mau, Soc Trang and Kien Giang were delayed comparing to other provinces due to the effects of drought and saltwater intrusion in the dry season. For the triple rice crop, the Winter-Spring season started planting
between November 5, 2018 and December 15, 2018 with area about 782,350 ha; the Summer-Autumn season started from March 20, 2019 to April 29, 2019 with an area of about 436,125 ha. The Autumn-Winter season started planting from July 5, 2019 to August 14, 2019 with a total area of 411,175 ha.

4. Conclusion

Results of evaluating the effectiveness of using NDVI time series show that NDVI MODIS MCD43A4 image series was effectively used in mapping the planting calendar of Winter-Spring season of 2018-2019 with the area error was less than 10% and the difference of planting date was reasonable for explanation. The results also show the limitations of the NDVI time series in extracting planting calendar of the Summer-Autumn and Winter-Autumn season in 2019. Research revealed the effectiveness of MODIS MCD43A4 imagery when used during the dry season (Winter-Spring season), however users need to be considered in used of the rainy season period due to great influence by clouds. Further studies on fusion of satellite images or methods to replace cloud-affected pixels need to be taken into consideration.

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