Rice yield estimation in An Giang province, the Vietnamese Mekong Delta using Sentinel-1 radar remote sensing data

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Abstract. Rice production in Vietnam has been developing rapidly and sustainably in recent years, contributing to ensuring national food security. However, it is facing the effect of climate change, sea-level rise, salinity intrusion, drought, and flood which threatens food production, especially in the Vietnamese Mekong Delta. For this reason, building a tool that allows estimating rice yield is necessary. SAR (Synthetic Aperture Radar) remote sensing data from Sentinel-1 satellites is provided by European Space Agency (ESA) with no cost, large coverage, and high spatio-temporal resolution, which has the advantage of observation in cloudy, foggy, rainy weather and independent of solar radiation. Therefore, this data is suitable for rice monitoring in countries with tropical monsoon climate like Vietnam. This paper presents the results of estimating the Winter-Spring rice yield in 2018 by using multitemporal Sentinel-1 data with C-band. The estimated rice yield was compared with the in-situ yield, which shows that the average values of the samples of estimated and surveyed yield were equivalent with 6.5 ton/ha and 6.6 ton/ha respectively, and the standard deviation between the estimated and surveyed yield was 0.80 ton/ha. The results demonstrate the applicability of the multitemporal SAR Sentinel-1 data for estimating rice yield in the study area, An Giang province, the Vietnamese Mekong Delta.

1. Introduction

Rice acreage and rice yield are important information that supports various policies on agriculture and food security [1–3]. Traditional rice monitoring surveying on land often costs lots of time and effort [2], which requires a high cost for resources mobilizing, especially when it is done on a large scale [3]. Optical remote sensing data is often used to estimate rice yield in the world and in Vietnam [4], however, it is limited by weather conditions. To overcome this limitation, radar remote sensing is a more affordable approach in terms of data availability, cost, time, and resources to provide data about rice-growing areas at various scales. Therefore, radar remote sensing data is an appropriate data source for agricultural surveillance in general and rice monitoring in particular in tropical regions [5,6].
The application of radar remote sensing data in rice monitoring has a great significance to provide an early warning tool of growth status information and timely support for food security policies [7–9]. Radar remote sensing is dominant for agricultural applications in the tropics and subtropics, especially since the high-resolution Sentinel-1 image data source is available free of charge. Sentinel-1 provides data with high temporal resolution (12 or 6 days/image) which is suitable for most near real-time agricultural monitoring applications.

The importance of rice production requires an effective rice monitoring system. Recent studies have demonstrated radar remote sensing’s ability to monitor rice [3] and estimate rice yield [2], including the ORYZA model [2,10] which has been using to estimate rice yield with high accuracy. However, the model requires a lot of ground data as input. In addition, there are a number of other methods using information extracted from radar data such as experimental regression [5,6,11], neural network [12], random forest [13]… in which, the most common method used is experimental regression models. Shao et al. [11] used a self-proposed model for the RADARSAT data, based on three different times in three different stages of rice growth and has 91% accuracy. Nguyen [6] estimated rice yield based on Sentinel-1 data using an experimental regression method. This paper presents the results of rice yield estimation based on a multivariate regression model between the VH (vertical transmit, horizontal receive) polarization backscattering values of Sentinel-1 data according to rice age and in-situ rice yield. Specific objectives of the study include i) determining multivariate regression equations to estimate rice yield from backscatter values corresponding to rice age; ii) implementing an accuracy assessment of the estimated rice yield map based on the field data.

2. Materials and Methods

2.1. Study area

The study area, An Giang province is in the zone from latitude 10°12’ to 10°57’N and longitude 104°46’ to 105°35’E (Figure 1). It is one of the leading provinces in terms of rice production area in the Vietnamese Mekong Delta, so this area was selected to test the application of radar remote sensing in monitoring rice area and estimating rice yield.
2.2. Data used

Sentinel-1 is a two-satellite constellation with the prime objectives of land and ocean monitoring. The goal of the mission is to provide C-Band SAR data continuity of the ERS-2 and Envisat mission ends [14]. Sentinel-1A and -1B satellites have a 6-day repeat cycle (in the study area) and a high spatial resolution of 20 m in the Interferometric Wide (IW) swath mode, which was used for this study. Sentinel-1 imagery data with VH polarization composed of 62 scenes acquired from November 1st to April 30th, 2018 during the Winter-Spring 2018 rice season in An Giang province.

This research collected field data at 60 sample fields (Figure 1) during the Winter-Spring season. The collected data included sowing date, harvest date, rice yield for each sample field. Rice yield per sample was harvested in a plot and the sample plot had dimensions of 0.5 x 0.5 m. The location of the sample fields was determined using a handheld GPS receiver (GARMIN-GPSMAP 76S, accuracy approximately about 10 m). These sample fields were randomly divided into two datasets: a training dataset of 41 samples (equivalent to 70%) and a validation dataset of 19 samples (equivalent to 30%).

2.3. Methods

This study evaluated the capability of rice yield estimation of Winter-Spring season by analyzing Sentinel-1 data and in-situ yield data, which has followed the steps as shown in Figure 2. The radar imagery was collected and analyzed through these steps: a) pre-processing; b) rice/non-rice mapping: applying the threshold method for multi-temporal data collected during the Winter-Spring season; c) extracting backscatter values according to rice age (day after planting - dap) at the sample fields; d) regression analysis; e) mapping estimated rice yield.
The collected data was pre-processed through the following steps: a) SAR data was calibrated to convert the digital values (DN – digital number) to backscattering coefficient; b) these images then got terrain correction to remove the effects of terrain by STRM DEM (Shuttle Radar Topography Mission digital elevation model) with 30 m resolution; c) multi-temporal filtering by the method proposed by Quegan et al. [15]; d) spatial filtering by speckle filter method [16].

The study used the threshold method for rice/non-rice mapping with multi-temporal data [6,17]. In addition, the rice age algorithm [9] was used to extract days after sowing/transplanting (rice age) in the sample fields. Based on previous studies that used experimental regression models [5,6], the study used multivariate linear regression analysis between polarizations and their ratio of multi-temporal radar data collected in one season with in-situ rice yield in that season. The study estimated rice yield based on a regression model between backscattering values (VH) of rice age and in-situ rice yield.

In order to validate the rice yield estimation model using radar remote sensing data, the results of rice yield estimation were compared with the validation dataset. We used statistical parameters such as mean value, root-mean-square error (RSME), percent error… to evaluate the results of estimated rice yield. RMSE has an ideal value of 0, which means that the estimated model has the best accuracy, however, this does not happen in practice, RMSE usually only reaches a certain acceptable expected value when applying the model. The RSME value is calculated using formula (1).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^2}$$  \hspace{1cm} (1)

In which $y_i$, $y$ are estimated value, and real value respectively; n is number of samples.

3. Results and Discussion

3.1. Rice yield estimation

After performing multivariate linear regression analysis between backscatter values and in-situ rice yield of 41 sample fields, we obtained the regression equation with a high correlation coefficient $R^2 = 0.60$.
and the standard deviation estimated of y value is 0.33 ton/ha. Multivariate linear regression equation between backscatter value corresponding to the growth period from 10 - 90 days after planting and rice yield are as follows:

\[ y = 8.751 + 0.101x_{10-20} + 0.034x_{20-30} - 0.016x_{30-40} + 0.123x_{40-50} - 0.336x_{50-60} + 0.073x_{60-70} - 0.007x_{70-80} + 0.151x_{80-90} \]

(2)

In which:

y: estimated rice yield (ton/ha).

x: backscatter value of rice field correspond to the day after planting. For example, \( x_{10-20} \) is backscatter values correspond to 10 - 20 dap, …

The distribution map of estimated rice yield for the Winter-Spring 2018 season in An Giang province is shown in Figure 3. The result of the estimated rice yield distribution shows the rice yield values primarily varies in the range of 5.0 to 8.0 ton/ha.

Figure 3. Distribution map of estimated rice yield for Winter-Spring 2018 season in An Giang province.
3.2. Accuracy assessment of estimated rice yield result

The reference dataset was collected from 19 sample fields for validating the model. The analytical results presented in Table 1 show the accuracy between estimated rice yield and in-situ rice yield, it shows that the average values of estimated yield and in-situ yield were similar, respectively 6.5 and 6.6 ton/ha. The RMSE between estimated yield and in-situ yield was 0.80 ton/ha. The results show that this model has the potential to estimate rice yield in the study area using Sentinel-1 data.

Table 1. Validation of estimated rice yield using Sentinel-1 data.

| No. | Sample | Estimated rice yield (ton/ha) | In-situ rice yield (ton/ha) | Percent error (%) |
|-----|--------|-------------------------------|-----------------------------|------------------|
| 1   | CP01   | 6.3                           | 6.8                         | -7.9             |
| 2   | CP03   | 7.4                           | 7.3                         | 1.4              |
| 3   | CP05   | 6.1                           | 5.8                         | 4.9              |
| 4   | CP06   | 7.4                           | 6.6                         | 10.8             |
| 5   | CP08   | 5.7                           | 6.6                         | -15.8            |
| 6   | CP09   | 7.1                           | 6.2                         | 12.7             |
| 7   | CT03   | 6.5                           | 7.4                         | -13.8            |
| 8   | CT04   | 6.1                           | 7.5                         | -23.0            |
| 9   | CT07   | 5.9                           | 6.6                         | -11.9            |
| 10  | CT10   | 6.9                           | 6.1                         | 11.6             |
| 11  | CT19   | 6.3                           | 7.1                         | -12.7            |
| 12  | CT20   | 6.3                           | 6.6                         | -4.8             |
| 13  | TS08   | 7.3                           | 6.2                         | 15.1             |
| 14  | TS11   | 6.5                           | 7.1                         | -9.2             |
| 15  | TS13   | 6.6                           | 7.1                         | -7.6             |
| 16  | TS17   | 5.5                           | 6.6                         | -20.0            |
| 17  | TS22   | 6.7                           | 5.8                         | 13.4             |
| 18  | TS26   | 6.2                           | 5.8                         | 6.5              |
| 19  | TS29   | 6.7                           | 5.8                         | 13.4             |
|     | Mean   | 6.5                           | 6.6                         | -1.2             |
|     | RMSE   | 0.80                          |                             |                  |

4. Conclusion

The study has shown that Sentinel-1 data has the capability to estimate rice yield, which is important information for agricultural production management and food security. The rice yield estimation model using Sentinel-1 data proved to be an effective method for estimating rice yield at a provincial scale. The result of validation which compared the estimated rice yield and the in-situ rice yield had high reliability. RMSE between estimated rice yield and in-situ rice yield was 0.80 ton/ha.

Research is being extended for the entire Vietnamese Mekong Delta, within the framework of a national-level project called “Applied research on optical and radar remote sensing data for rice planted area monitoring and rice yield, production estimation in the Mekong Delta and Red River Delta” and Asian Rice Crop Estimation & Monitoring (Asia-RiCE) component for the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) initiative.
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