# REGIONAL YIELD ESTIMATION FOR RICE CROP USING TIME-SERIES MODIS AND ENVISAT ASAR DATA: A CASE STUDY IN THE MEKONG DELTA, VIETNAM

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## ABSTRACT

*Viet Nam is the second largest (after Thailand) rice exporter in the world. The Mekong Delta (MD) located in the South Vietnam is the rice key region. It annually produces approximately half of the country's rice production. This study was to develop an approach for rice crop yield estimation in MD using MODIS EVI time-series and ENVISAT ASAR wide-swath mode data. The data were processed for 2007-2008 rice cropping seasons. The methodology of this study comprises four main steps: (1) constructing time-series Enhanced vegetation index (EVI) derived from MODIS images, (2) noise filtering of the EVI time-series data with the wavelet transform and speckle noise reduction of ASAR data using Enhanced Lee filter, (3) establishing rice crop yield models using quadratic model, and (4) model validation. The results demonstrated that the rice crop yield in MD could successfully predicted by a quadratic model with combination of two variables: EVI and backscattering extracted from ASAR images. The high determination coefficients ($R^2$) were obtained with $R^2$ of 0.81 for the first crop (winter-spring) and 0.80 for the second crop (summer-autumn) in 2007; and $R^2$ were 0.74 and 0.73 for rice crops in 2008, respectively. The predicted results were compared with the rice yield statistics indicated that the fitted model produced the close agreement between predicted and yield statistics. In 2007, the comparative results showed that the root mean square error (RMSE) were only 0.6 ton/ha (10.8%) for the first crop and 0.5 (12.0%) ton/ha for the second crop. And in 2008, RMSE were 0.5 ton/ha (7.2%) and 0.4 ton/ha (9.0%) for first and second crops, respectively. This study demonstrates the validity of the developed model using MODIS time series EVI combined with ASAR data for forecasting rice crop yields in the Mekong Delta prior to the harvesting period.*

***Keywords**: Rice yield, Forecasting, Mekong Delta, MODIS, ENVISAT ASAR, Quadratic model.*

## 1. INTRODUCTION

Crop monitoring is a critical work for the economic development and food security of any country in the world. The annual crop's production and yield estimation have directly impacted on national economic and food supply, especially, in Viet Nam where rice cultivation is one of the major economic activities. Therefore, getting early and high accuracy information in rice yield estimation in this region is essential for making decision in agricultural management and policy development.

Traditionally, the rice yield/production prediction is mainly based on ground survey data. It is often time-consuming, expensive and bias. Today, the remote sensing data has been considered as a suitable alternative for crop monitoring and crop yield prediction in regional and global scales. MODIS data was proved as a good candidate for applications on regional scale with high spectral and temporal resolution. The EVI index has been considered as a modified NDVI with improved sensitivity to high biomass area and improved capability for vegetation monitoring and reduce atmospheric influences (Huete and Justice, 1999). EVI was found to be more linearly correlated with green leaf area index (LAI) in crop fields (Boegh et al., 2002;

Chen, Vierling, and Derring 2005) and less prone to saturation high biomass regions (Huete et al., 2006; Xiao et al., 2004) in comparison with NDVI.

In addition, the backscattering coefficients extracted from ENVISAT ASAR wide-swath mode data was also used in this study. The radar backscattering coefficient was found that strongly correlated to rice plant height, rice biomass during the vegetative stage and reaches a saturation level at the reproductive stage (Ribbes and Le-Toan 1999a) and can be successfully used to estimate rice crop yield (Kajalainen et al., 2000, Kropff et al., 1994). The relationship between the backscatter coefficient and biomass of rice was investigated for development of prediction model with more than 90% of accuracy check (Li et al., 2003).

In this study, the quadratic model was used to predict rice crop yield in the Mekong Delta, Vietnam. The main objective of this study was to develop a model using MODIS EVI and ASAR backscattering coefficients to predict rice crop yield for the two main crops: winter-spring and summer-autumn in MD, Vietnam at the heading date.

## 2. STUDY AREA

The study area (Mekong Delta) located in the Southern Vietnam from 08$^o$ 30’ to 11$^o$ 00’ N and 104$^o$ 05’ to 107$^o$ 00’ E, covers approximately 40,000 km$^2$ (Figure 1).

The study area has a humid subtropical monsoon climate with an annual mean temperature about 27$^o$C. The mean temperature varies from 23−25$^o$C during the coolest months (December and January) to more than 33$^{\circ}$C during the warmest months (March and April). There are two distinct dry and wet seasons. Wet season starts from May to November and dry season is from December to April.

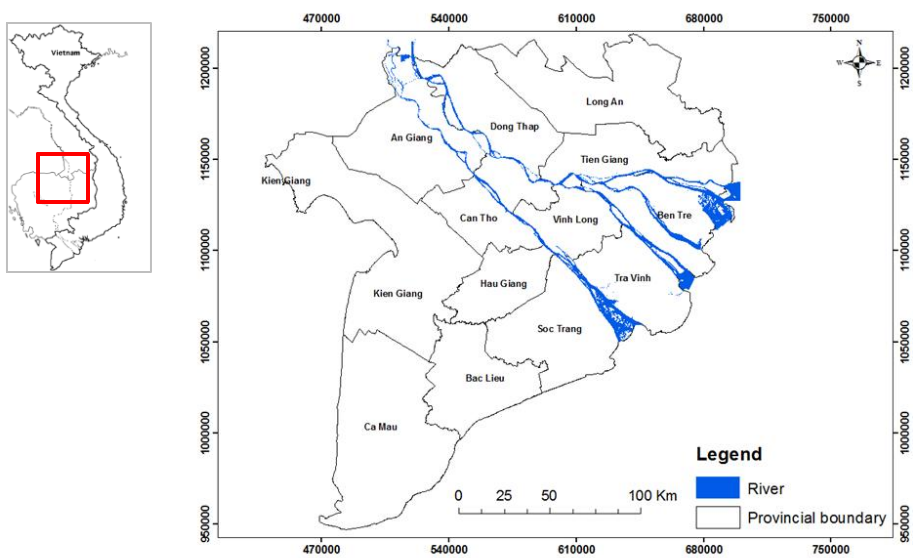



**Figure 1: Map of the study area relative to national geography**

## 3 DATA

### 3.1 MODIS Data

MODIS (Moderate Resolution Imaging Spectraradiometer) is a key instrument abroad the Terra and Aqua satellites which can view the entire Earth’s surface daily. In this study, the eight-day MODIS land surface reflectance product (MOD09A1) with spatial resolution of 500m was used to develop prediction model for rice crops in the Mekong Delta.

### 3.2 ENVISAT ASAR Data

ASAR is one of instrument on broad the ENVISAT satellite. The standard product available for wide-swath (WS) mode is a 150 m resolution and 405 km swath width at 35-day repeat interval. Since ASAR data used is monthly data, there were only three images acquired during a rice life cycle. In this study, the single image acquired in the middle of rice crop during the growing stage and closest to the heading date observed from MODIS time-series data was used to test the correlation and estimated rice crop yield (Table 1).

**Table 1. List of ENVISAT ASAR data used**

| Sensor | Observation date | | Rice crop |
|---|---|---|---|
| | 2007 | 2008 | |
| ENVISAT ASAR (HH polarization) | 2007/01/16 | 2008/02/05 | Winter - Spring |
| | 2007/05/29 | 2008/06/08 | Summer - Autumn |

### 3.3 Rice crop yield statistics and rice crop map

The rice crop yield statistics at the district level were collected from Provincial Departments of Statistics for rice cropping seasons (i.e., winter-spring and summer-autumn seasons) in 2007 and 2008. The land-use/land-cover (LULC) map (scale: 1/125.000) in 2006 was used to mask out non-rice areas..

## 4 METHODS

### 4.1 MODIS Time-series EVI Construction

In order to construct time-series EVI data, each 8-day MODIS EVI image was first calculated. Totally, 100 images were generated then those images were stacked into one 8-day composite scene.

The EVI index was calculated using the following form:

$$EVI = 2.5\ x \frac{NIR - RED}{NIR + 6\ \times RED - 7.5\ \times BLUE + 1} \quad (1)$$

where, NIR, RED, and BLUE are atmospherically or partially-atmospherically corrected surface reflectance of near infrared, red, and blue bands, respectively.

### 4.2 Noise filtering of time-series MODIS EVI data.

In this study, the wavelet transform was used to filter out noise from the time-series EVI data from 2007 to 2008 which has been proved as a suitable filter for noise removal of time-series data (Chen et al., 2011; Zhang Shengwei et al., 2011; Addison, 2002).). The wavelet transform decomposes a signal into a set of basic functions which are called wavelets and is defined as follows:

$$W(s,\tau) = \frac{1}{\sqrt{a}} \int x(t)\, \psi \left(\frac{(t-\tau)}{s}\right) dt, \quad (2)$$

where $\psi$ implies a mother wavelet, and x represents the time-step in the one-dimensional time series over which integration is performed $s$ and $\tau$ are scaling and translation parameters.

### 4.3 Speckle noise reduction for ENVISAT ASAR Data

The Lee Enhanced filter was applied to reduce speckle noise on ENVISAR ASAR wide-swath mode images in this study.

The Enhanced Lee filter is defined as following:

$$W_{(x,y)} = e^{-K_d \frac{C_I(x,y) C_{si}}{C_{max} - C_I(x,y)}} \quad (3)$$

where: $W_{(x,y)}$ is weighting function; $C_{si}$ is standard speckle index; $C_I$ is varied standard speckle index; $C_{max}$ is the upper threshold; $K_d$ is called damping factor.

### 4.5. Non-rice area masking

The non-rice areas were masked out from time-series MODIS EVI data using land-use/land-cover map. The pixels that are located in the remaining rice areas were used to establish rice yield prediction model. In order to remove mixed-pixels, the 500m resolution vector grid was generated for the rice crop map and then calculated the percentage covers by rice crop for each pixel. The pixels with more than 90% covered by rice crop were used to develop rice yield prediction models. In addition, the pixels with EVI values lower than 0.35 were excluded from the analysis.

### 4.6. Establishment of rice yield models

In this study, 60 districts were sampled to establish rice yield models based on cropping calendar (Figure 2). Of these 60 sampling districts, 40 districts were used to develop rice yield prediction models for first crop and 30 districts for second crop. The other 20 districts were used for model validation. The selected sampling districts are mostly homogenous rice areas and mainly practiced two rice crops per year. The quadratic models were used in this study to estimate rice crop yields. The format of quadratic models as following:

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 \quad (4)$$

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \beta_4 X_1^2 + \beta_5 X_2^2 \quad (5)$$

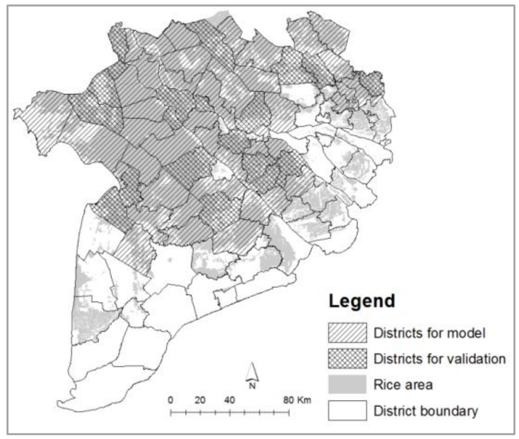



**Figure 2: Location of sampling districts**

Where Y is predicted rice crop yield

$\beta_{0-5}$ are model coefficients

$X_{1-2}$ are input variables

### 4.6. Model validation

To test the robustness and the ability of the generated regression model to estimate rice crop yield, the established models were used to estimate the rice crop yield in 2007 and 2008 for other 20 districts (Figure 2). The performance of prediction models was assessed using root mean square error (RMSE), the mean absolute error (MAE), and the mean bias error (MBE). Those are calculated using formulas as following:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i' - y_i)^2}, \quad (6)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i' - y_i| \quad (7)$$

$$MBE = \frac{1}{n}\left[\sum_{i=1}^{n} y_i' - y_i\right] \quad (8)$$

where n is number of districts used for validation, $y_i'$ is the predicted yields, and $y_i$ is the actual rice yield statistics.

## 5 RESULTS AND DISCUSSION

### 5.1 Noise filtering result

The noise is significantly mitigated on the time-series EVI data after noise filtering. The smoothed time-series EVI profiles can show the temporal pattern characteristics of rice cropping system throughout the year and the characteristic points including maximum point and inflection point can be identified (Figure 3).

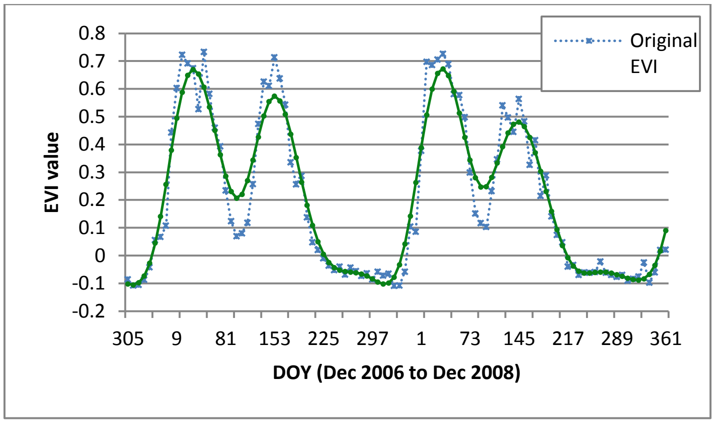
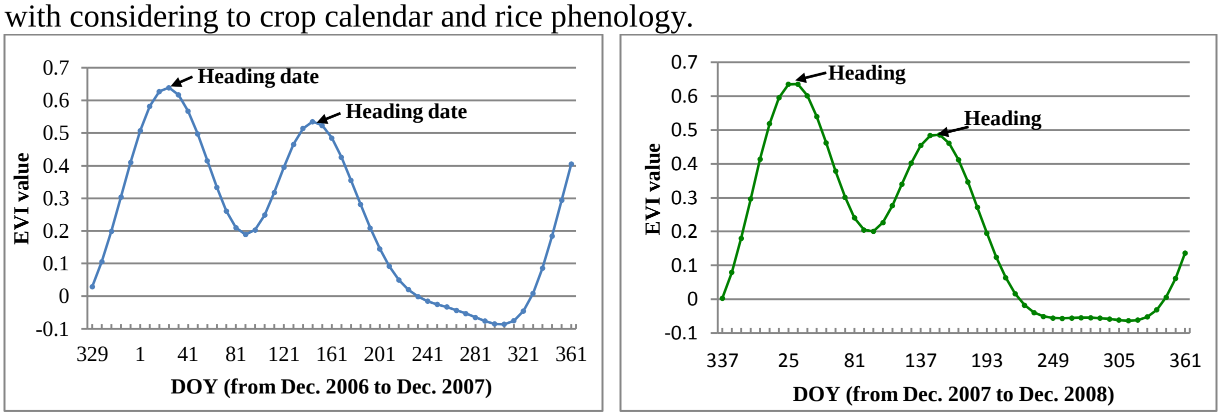



**Figure 3.The EVI profile of double-cropped irrigated rice signature before and after noise filtering (from Nov 2006 to Dec 2008)**

### 5.2 Temporal characteristics of time-series EVI profile

The smoothed EVI profiles show the temporal pattern characteristics of double rice in 2007 and 2008. There were two peaks observed from time-series profiles indicating two crops practiced per year. For 2007, the first peak indicated the first crop (winter-spring crop season) appears around day of year (DOY) 025 and the second peak which related to second crop (summer- autumn), was DOY 145 (Figure 4a). For 2008, these two peaks were identifed around DOY 033 and 153 for first crop and second crop, respectively (Figure 4b). Once the heading date was identified from time-series data, it is possible to estimate the sowing and harvesting date with considering to crop calendar and rice phenology.




(a) (b)

**Figure 4. The EVI profile shows the double-cropped irrigated rice pattern in 2007 (a) and 2008 (b)**

### 5.3 Rice yield prediction models

The yield prediction models for rice crop were established using different input variables to test the applicable ability of each one for the purpose of rice yield estimation. The results of quadratic regression analyze between different input parameters and yield statistical data at district level were presented in Table 1 for 2007 and Table 2 for 2008.

All fitted models for two main crops in 2007 and 2008 having p-value <0.05, indicated that there was less than 5% chance of prediction results came from the same group. The comparison showed that the model used combination of EVI and backscattering coefficients provided the best result with highest R-square of 0.81 for winter-spring crop and 0.80 for rice crop in 2007; 0.74 and 0.73 for two crops in 2008, respectively (case 3, Table 2, 3) . This result revealed that the crop yield is largely governed by variables considered in models.

The Durbin-Watson statistic value that was calculated for each developed model varied from 1.73 to 2.49. It is demonstrated that there is no significant autocorrelation in the residuals of regression analysis. There exists enough evidence to conclude that the fitted models can be used to predict rice crop yield in the study area.

**Table 2: Results quadratic regression model analysis between rice crop yield and indicators for the rice crops in 2007.**

| **Winter – Spring crop in 2007** | | | | | |
|---|---|---|---|---|---|
| **Cases** | **Input variables** | **Yield prediction models** | **$R^2$ between observations** | **Durbin-Watson statistic** | **F-statistic** |
| 1 | EVI | $Y = -7.76 + 41.32*EVI - 26.93*EVI^2$ | 0.78 | 1.987 | 66.38 |
| 2 | Backscattering Coefficients | $Y = 1.17 + 8.08*ASAR + 20.0*ASAR^2$ | 0.39 | 2.095 | 10.36 |
| 3 | Combination of EVI and backscattering | $Y = -15.72 + 73.31*EVI – 4.406*ASAR – 60.97*(EVI*ASAR) – 39*EVI^2 + 61.23*ASAR^2$ | 0.81 | 2.49 | 28.38 |
| **Summer – Autumn crop in 2007** | | | | | |
| 1 | EVI | $Y = 2.78 + 3.53*EVI + 2.04*EVI^2$ | 0.73 | 1.27 | 33.56 |
| 2 | Backscattering Coefficients | $Y = 1.91 + 8.61*ASAR - 4.32*ASAR^2$ | 0.65 | 1.86 | 25.27 |
| 3 | Combination of EVI and backscattering | $Y = 1.13 + 17.269*EVI – 6.44*ASAR – 79.41*(EVI*ASAR) + 21.39*EVI^2 + 52.29*ASAR^2$ | 0.80 | 1.73 | 18.62 |

**Table 3: Results quadratic regression model analysis between rice crop yield and indicators for the rice crops in 2008.**

| **Winter – Spring crop in 2008** | | | | | |
|---|---|---|---|---|---|
| **Cases** | **Input variables** | **Yield prediction models** | **$R^2$ between observations** | **Durbin-Watson statistic** | **F-statistic** |
| 1 | EVI | $Y = -15.10 + 74.08*EVI – 61.78*EVI^2$ | 0.67 | 1.85 | 19.43 |
| 2 | Backscattering Coefficients | $Y = -4.07 + 45.9*ASAR - 45.52*ASAR^2$ | 0.53 | 2.31 | 20.54 |
| 3 | Combination of EVI and backscattering | $Y = -8.97 + 60.21*EVI – 17.24*ASAR + 102.93*(EVI*ASAR) – 84.95*EVI^2 – 44.05*ASAR^2$ | 0.74 | 1.92 | 16.22 |
| **Summer – Autumn crop in 2008** | | | | | |
| 1 | EVI | $Y = -15.61 + 84.92*EVI – 85.04*EVI^2$ | 0.63 | 2.28 | 20.05 |
| 2 | Backscattering Coefficients | $Y = 3.31 + 3.37*ASAR + 2.37*ASAR^2$ | 0.64 | 2.73 | 18.65 |
| 3 | Combination of EVI and backscattering | $Y = -17.81 + 124.18*EVI – 71.25*ASAR + 18.21*(EVI*ASAR) – 137.83*EVI^2 + 197.04*ASAR^2$ | 0.73 | 2.39 | 2.39 |

### 5.4 Predictive performance assessment

The performance of prediction models was assessed using rice crop yield statistic obtained for 20 districts (Figure 2). The developed models were used to predict rice crop yields for these 20 districts in two main crops (winter-spring and summer-autumn crops) in 2007 and 2008 (Table 4, 5). The best model that uses combination of EVI and backscattering as input variable was selected to predicted rice crop yield.

In 2007, the RMSE was 0.74 ton/ha (10.58%) and MAE value was 11.47% for the winter-spring crop, demonstrated the consistency between the rice yield statistic and predicted yields. For the summer-autumn crop, the RMSE and MAE were 0.47 ton/ha (11.47%) and 9.99%, respectively indicating the close agreement between rice yield statistic and predicted yields obtained from established models. The MBE values were -3.30% for the first crop that indicated slightly under-estimation result and 7.79% for the second crop revealed over-prediction (Table 4).

**Table 4. Comparison of predicted and actual yield for crops in 2007 obtained from quadratic model using combination of two variables: EVI and ASAR.**

| | | **Winter-Spring crop in 2007** | | | **Summer-Autumn crop in 2007** | | |
|---|---|---|---|---|---|---|---|
| *ID* | *Districts* | *Actual (ton/ha)* | *Predicted (ton/ha)* | *Relative error (%)* | *Actual (ton/ha)* | *Predicted (ton/ha)* | *Relative error (%)* |
| 1 | An Bien | 4.5 | 5.34 | 18.73 | 3.89 | 4.46 | 14.55 |
| 2 | An Phu | 7.83 | 7.05 | -9.94 | 5.02 | 5.45 | 8.53 |
| 3 | Chau Doc | 6.98 | 7.28 | 4.33 | 5.32 | 5.63 | 5.87 |
| 4 | Chau Thanh(AG) | 7.41 | 6.54 | -11.76 | 5.4 | 5.37 | -0.62 |
| 5 | Chau Thanh (DT) | 6.61 | 5.81 | -12.04 | 3.99 | 4.34 | 8.89 |
| 6 | Chau Thanh (KG) | 6.08 | 5.94 | -2.33 | 4.68 | 5.16 | 10.31 |
| 7 | Cho Gao | 6.91 | 6.63 | -4.09 | 5.23 | 5.54 | 5.86 |
| 8 | Long Xuyen | 7.61 | 6.79 | -10.84 | 5.61 | 5.46 | -2.72 |
| 9 | O Mon | 6.67 | 6.59 | -1.19 | 4.08 | 5.04 | 23.56 |
| 10 | Tam Binh | 6.14 | 5.83 | -5.03 | 4.6 | 4.88 | 6.07 |
| 11 | Tam Nong | 6.79 | 6.99 | 2.99 | 4.67 | 5.57 | 19.29 |
| 12 | Tan Hung | 5.78 | 6.23 | 7.81 | 4.09 | 4.68 | 14.41 |
| 13 | Thanh Hoa | 5.85 | 5.50 | -5.96 | 2.9 | 3.53 | 21.78 |
| 14 | Tinh Bien | 6.46 | 7.39 | 14.37 | 5.29 | 5.36 | 1.33 |
| 15 | Tra On | 6 | 5.37 | -10.42 | 4.43 | 5.04 | 13.80 |
| 16 | Tri Ton | 6.12 | 6.66 | 8.80 | 5.41 | 5.26 | -2.83 |
| 17 | TX. Cao Lanh | 6.59 | 5.84 | -11.43 | 4.53 | 5.10 | 12.49 |
| 18 | Vung Liem | 6.19 | 5.30 | -14.42 | 4.62 | 4.94 | 6.94 |
| 19 | Can Giuoc | 2.08 | 3.93 | -1.77 | 3.57 | 3.39 | -5.04 |
| 20 | Phung Hiep | 4 | 3.12 | -21.96 | 4.70 | 4.56 | -3.05 |
| | **RMSE** (ton/ha) | **0.74** | | | **0.47** | | |
| | **RMSE** (%) | **10.58** | | | **11.47** | | |
| | **MAE** (%) | **0.63** | | | **0.40** | | |
| | **MBE** (%) | **-3.30** | | | **7.97** | | |

In 2008, the RMSE were 0.51 ton/ha (8.39%) and 0.81 ton/ha (9.07%) for winter-spring and summer-autumn rice crops, respectively, that demonstrated the good prediction results. The MAE values were 0.47% and 0.58% for two main crops, respectively, showed over-estimation in both crop seasons in 2008. MBE values were -0.53% for winter-spring crop, indicated slightly under-estimation, while in the summer-autumn crop, the MBE value of 0.26, indicated over-prediction (Table 4). Those results were clear that there was a good correlation between the predicted yield and the rice yield statistics in term of several traditional validation methods.

The prediction result for the second crop (summer-autumn crop) was normally observed with larger errors than that of the spring-winter crop. The reason is the summer-autumn was practiced during rainy season; hence, the variations of weather as well as rice diseases can cause rice crop yield reduction. Moreover, the satellite data acquired in the wet season were often contaminated by cloud cover and atmospheric conditions, it is also contribute and create some errors to the prediction results.

**Table 5. Comparison of predicted and actual yield for crops in 2008 obtained from quadratic model using combination of two variables: EVI and ASAR.**

| | | **Winter-Spring crop in 2008** | | | **Summer-Autumn crop in 2008** | | |
|---|---|---|---|---|---|---|---|
| *ID* | *Districts* | *Actual (ton/ha)* | *Predicted (ton/ha)* | *Relative error (%)* | *Actual (ton/ha)* | *Predicted (ton/ha)* | *Relative error (%)* |
| 1 | An Bien | 5.40 | 4.68 | -13.33 | 4.19 | 3.51 | -16.08 |
| 2 | An Phu | 7.92 | 6.98 | -11.87 | 5.70 | 5.61 | -1.59 |
| 3 | Chau Doc | 7.38 | 6.88 | -6.78 | 5.60 | 4.94 | -14.04 |
| 4 | Chau Thanh(AG) | 7.45 | 6.91 | -7.25 | 5.75 | 4.46 | -5.16 |
| 5 | Chau Thanh (DT) | 7.04 | 6.50 | -7.67 | 4.71 | 4.65 | 16.07 |
| 6 | Chau Thanh (KG) | 6.93 | 6.96 | 0.43 | 4.01 | 4.65 | -16.07 |
| 7 | Cho Gao | 7.06 | 6.69 | -5.24 | 5.33 | 5.31 | -6.90 |
| 8 | Long Xuyen | 7.50 | 6.88 | -8.27 | 5.70 | 4.73 | 9.75 |
| 9 | O Mon | 6.78 | 6.85 | 1.03 | 4.31 | 5.20 | 7.91 |
| 10 | Tam Binh | 6.32 | 6.30 | -0.32 | 4.82 | 5.63 | 9.01 |
| 11 | Tam Nong | 6.70 | 7.36 | 9.85 | 5.17 | 5.02 | 5.50 |
| 12 | Tan Hung | 5.97 | 6.73 | 12.73 | 4.76 | 3.55 | 14.42 |
| 13 | Thanh Hoa | 5.83 | 5.79 | -0.69 | 3.10 | 5.43 | -0.81 |
| 14 | Tinh Bien | 6.86 | 6.91 | 0.73 | 5.47 | 4.74 | -1.91 |
| 15 | Tra On | 6.42 | 6.07 | -5.45 | 4.83 | 5.23 | 9.23 |
| 16 | Tri Ton | 6.60 | 6.98 | 5.76 | 4.79 | 4.82 | -0.11 |
| 17 | TX. Cao Lanh | 6.66 | 6.31 | -5.26 | 4.82 | 4.72 | -1.67 |
| 18 | Vung Liem | 6.29 | 6.28 | -0.16 | 4.80 | 5.32 | -4.97 |
| 19 | Can Giuoc | 3.65 | 4.17 | 14.40 | 3.53 | 3.57 | 1.13 |
| 20 | Phung Hiep | 5.22 | 6.09 | 16.66 | 4.67 | 4.75 | 1.63 |
| | **RMSE** (ton/ha)<br>**RMSE** (%)<br>**MAE** (%)<br>**MBE** (%) | **0.51**<br>**8.39**<br>**0.47**<br>**-0.53** | | | **0.81**<br>**9.07**<br>**0.58**<br>**0.26** | | |

## 6 CONCLUSIONS

From the findings, it could be concluded that the MODIS-EVI and ASAR data could be successfully used for crop yield prediction in MD before the harvesting period. It was shown that, the parameters considered in models EVI and ASAR strongly correlated with rice crop yield statistics. The quadratic model using two variables (EVI and ASAR) provided the highest correlation between indicators and rice crop yields. There was significantly increasing the correlation coefficients from the model using combination of EVI and ASAR with $R^2$ of 0.81 and 0.8 for winter-spring and summer-autumn crops in 2007; for crops in 2008 the $R^2$ were 0.74 and 0.73, respectively. The yield estimation also has been made with higher accuracy compared to the model used single variables EVI or ASAR individually. The percentage differences of the predicted yield from the actual yield is within acceptable limit (roughly 10%), indicating the close agreement between rice yield statistics and rice predicted yields.

The results confirmed the validity of methods used in this study for estimating rice crop yields in the Mekong Delta (Vietnam) before harvesting. The developed model could be become an useful farming tool for local agriculture management and transfer to other regions.

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