RICE CROP CLASSIFICATION FROM MODIS IMAGERIES USING SOFT AND HARD CLASSIFIERS

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ABSTRACT: Information on rice growing areas is important for crop production estimation. This study investigated the applicability of the linear mixture model (LMM) and support vector machines (SVM) to classify rice cropping systems in the Vietnamese Mekong Delta using MODIS data. Data were processed for 2006 comprising three main steps: (1) data pre-processing to generate smooth time-series NDVI data, (2) rice crop classification using LMM and SVM, and (3) classification accuracy assessment using the ground reference data and rice area statistics. The classification results indicated that SVM yielded slightly more accurate results than LMM. The overall accuracy and Kappa coefficient achieved by LMM were 79.9% and 0.73, while those by SVM were 85.1% and 0.80, respectively. The Z-test based on Kappa statistics reported the value of 0.275 smaller than 1.96, indicating no significant difference between the two methods. The comparison results between the MODIS-derived rice area and rice area statistics also affirmed close agreement (R^2>0.8), in both cases.

1. INTRODUCTION

Vietnam is the second largest rice supplier in the word. The majority of rice in this country was produced in the Mekong Delta. This region has been documented to be one of the most low-lying coastal deltas most vulnerable from impacts of climate change. Because rice is an importantly economic and staple food crop in providing employment and livelihood for large populations in rural areas, monitoring rice producing areas becomes vitally necessary due to the official initiatives to ensure food security and supply. During the last few decades, rapid population growth along with urbanization at an unprecedented rate have been narrowing arable land for rice production and triggering the more intensive rice cultivation, consequently resulting in environmental impacts including land degradation.

Considering these socioeconomic and environmental aspects, rice production must be produced in a way that could balance between food needs and environmental safeguards. Thus, there was a need to develop an effective rice crop monitoring program. Remote sensing is an important tool for this monitoring purpose because it can provide spatio-temporal coverage. MODIS data are a reliable data source for crop monitoring at a large scale because it can be acquired on a regular basis with a wide coverage. Studies have used MODIS data for rice crop monitoring (Chen et al., 2012; Chen et al., 2011b; Chen et al., 2011c; Mingwei et al., 2008). Because MODIS data were often obscured by clouds. Thus, it is essential to remove such noise from the data prior to the analysis. In this study, we used the time-series NDVI data for rice crop mapping, and the wavelet transform was applied to filter noise from the time-series data.

Because the size of rice fields in the study area was generally smaller than a MODIS pixel, the mixed-pixel issues led to difficulties for the classification. Thus, sub-pixel soft and hard classifiers including linear mixture model (LMM) and support vector machines (SVM) were comparatively tested for rice crop classification. The LMM quantifies the fractions of different targets within the image pixel (Adams et al., 1986), while SVM (Boser et al., 1992; Cortes and Vapnik, 1995; Vapnik, 1999b) is based on statistical learning theory using a kernel function to non-linearly project the training data in the input space into a higher dimensional space where the classes are linearly separable.

The main objective of this study was to develop an approach to classify rice cropping patterns from MODIS time-series NDVI data using LMM and SVM in the Vietnamese Mekong Delta.

2. STUDY AREA

The study area (Figure 1) lying between 8.5-11.0^0 N and 104.5-106.64^0 E covers an area of approximately 40,000 km^2. The climate is tropical monsoonal with two distinct seasons: rainy season (May−Oct) and dry season (Nov−Apr). Rice is the main economic crop and rice production was classified into four cropping seasons: rainy season (Jul−Aug to Dec−Jan), winter−spring (Nov−Mar), summer−autumn (Mar−Jul) and autumn−winter (Jul−Nov). Three rice cropping systems were observed: single−cropped rain−fed rice, (2) double−cropped rice, and (3) triple−cropped rice. The single−cropped rice used long−term varieties (150−180 days), while the double− and triple−cropped irrigated rice used short−term varieties (90−100 days).

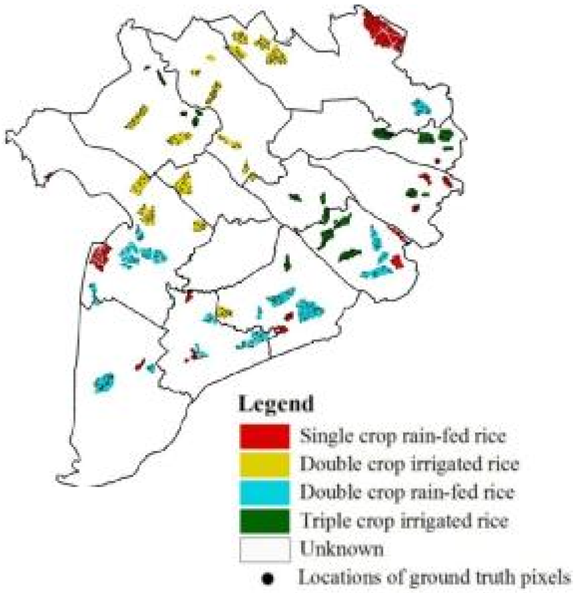

Figure 1. Map of the study area showing the locations of ground reference sites created after the 2006-2007 field surveys. The black dots were used for accuracy assessment.

2. DATA

The 8-day MODIS data (MOD09Q1) were used for rice crop classification. This product has two spectral bands (red and near infrared) with the resolution of 250 m. We also collected MOD09A1 product (MOD09A1) that include seven spectral bands with 500 m resolution. The blue band of this product (MOD09A1) was used for cloud masking purpose. The MODIS data have been geometrically and radiometrically corrected. Thus, it can be used for scientific publication. The 2002 land-use map of the study area (scale: 1/250,000) was used as a reference source for investigating rice fields and preparing the ground reference image (Figure 1). Rice area statistics obtained from the Vietnamese General Statistics Office for 2006 were used for regression analysis between MODIS-derived area and rice area statistics.

2. METHODS

2.1 Data pre-processing

The time-series NDVI data (46 bands) were fist constructed. The data contained noise due to clouds. We filtered this noise using a two−step procedure: (1) the pixels covered by thick clouds were first removed using the blue band, where its reflectance value was greater than 0.2. The missing values were replaced with new values from the time-series profile using the linear interpolation; (2) the wavelet transform (using Coiflet 4) widely used to filter time-series vegetation indices (Chen et al., 2011a; Chen et al., 2011b; Galford et al., 2008) was applied to smooth the time-series data.

2.2 Image classification

The LMM was applied to the filtered time-series NDVI data for rice crop classification. This method can be expressed using the following form.

$$r = M\alpha + e,$$

where r is a vector representing the temporal NDVI value for a column pixel vector of the temporal band n; M is a $n \times c$ signature matrix of endmember c in the band n; and e is the error term. Inverting the equation above is possible to estimate the abundance fractions of endmembers. The LMM represents an unconstrained linear mixing problem (abundance sum-to-one and abundance non-negativity) can be solved using the least squares approach (Heinz and Chang, 2001). The classification results (values from 0−1) were hardened to convert the abundance estimation of a mixed pixel to a pure pixel with respect to a desired rice class.

The SVM was also applied for rice crop classification to compare its classification performance with LMM. The SVM used training samples for classification. The algorithm projects the training data into a high dimensional space using a kernel function, where the classes can be separable. In this study, the radial basis function was used because it gives more accurate classification results in comparison with linear and polynomial kernels (Camps-Valls and Bruzzone, 2005). Details about SVM algorithm can be found in the text of The Nature of Statistical Learning Theory (Vapnik, 1999a), and are thus not repeated here.

2.3 Training data selection

The training data were selected using the ground reference data and the information recorded from the field surveys during 2006-2007. Because the size of rice fields in the study area was small (from less than one to several ha), to ensure that the training data were pure/near pure, the fuzzy composition method was used to categorize the pixels selected from homogeneous rice fields into several classes. The class whose NDVI values showed strong correlation ($R^2 > 0.9$) was selected. For LMM, the selected patterns for each class were averaged and then used as endmember input for the classification. Eventually, 12 endmembers (single crop rain-fed rice = 2; double crop irrigated rice = 4; double crop rain-fed rice = 2; triple crop irrigated rice = 4) were extracted for the LMM classification. For SVM, after analysing, evaluating and removing confused training patterns, 535 patterns (single crop rain-fed rice = 54; double crop irrigated rice = 167; double crop rain-fed rice = 196; triple crop irrigated rice = 118) were selected for classification.

2.3 Accuracy assessment

The post-classification refinement was taken to merge the classes having categories into a desired class. The majority filter was applied to reduce the ‘salt-and-pepper’ effect of the classified maps. The classified maps were verified using the ground reference image (Figure 1) and rice area statistics. 500 pixels for each class were randomly generated from the ground reference image for accuracy check. A significance test of difference between two classifiers (LMM and SVM) was also performed using the Z-test. We also compared the MODIS-derived rice area with the rice area statistics.

3. RESULTS AND DISCUSSION

The classification results obtained from LMM and SVM showed the comparative results (Figure 2). The double irrigated rice cropping was more concentrated in the upper region of the study area, while the triple rice cropping was mainly distributed in the middle of the study area between the rivers. The single and double rain-fed rice cropping systems were common in coastal areas where irrigation and soils had major constraints for short-term rice cultivation.

The comparison results between the ground reference data and classified maps exhibited that SVM gave slightly better classification results than LMM. The overall accuracy and Kappa coefficient achieved by LMM were 79.9% and 0.73, while those by SVM were 85.1% and 0.80, respectively (Table 1). However, the classification accuracy between the two methods was not different because the Z-test reported a value of 0.275, which was smaller than the critical value ($Z_{\alpha/2} = 1.96$). Of 2,000 ground reference pixels checked to determine the accuracy in each class, the single and double rain-fed rice classes had lower producer accuracy. This could be explained that the size of rice fields of these two classes was small and scattered throughout the region. The effects of mixed pixel problems caused small rice parcels to be easily omitted from the interpretation results.

The comparison between the classification results and rice statistics reaffirmed close agreement between the two datasets at the provincial level. The correlation coefficient (R^2) achieved by comparisons between the LMM-derived classification results and the rice area statistics was 0.90 (RMSE = 535.3 km^2), while the value achieved for SVM was 0.88 (RMSE = 522.2 km^2), respectively (Figures 3).

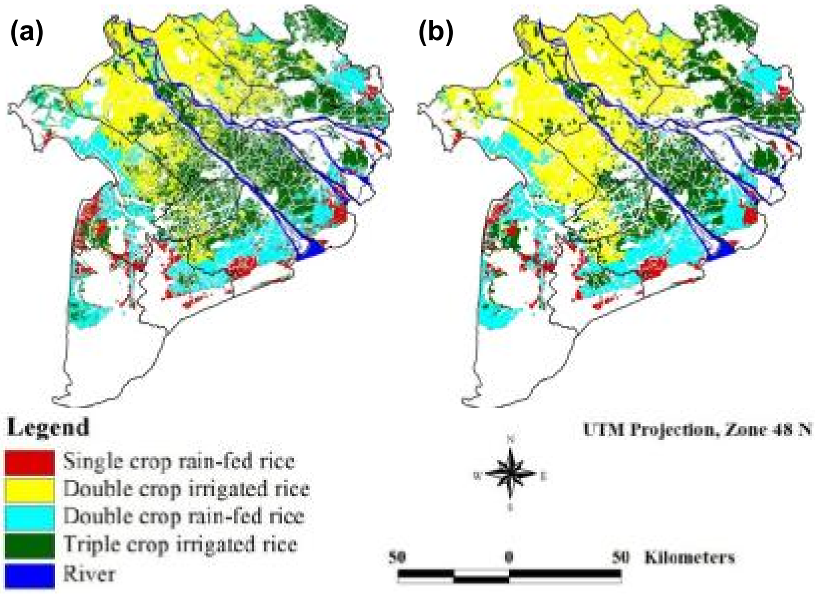

Figure 2. Results achieved by classification of the time-series MODIS NDVI data using: (a) LMM, and (b) SVM.

Table 1. Results of classification accuracy assessment.

Ground reference data (pixels)	Classification results (pixels) Single rain-fed rice	Double irrigated rice	Double rain-fed rice	Triple irrigated rice	Total
LMM					
Single rain-fed rice	328	5	42	125	500
Double irrigated rice	0	390	35	75	500
Double rain-fed rice	78	7	393	22	500
Triple irrigated rice	0	2	12	486	500
Total	406	404	482	708	2,000
Producer accuracy (%)	65.6	78.0	78.6	97.2	
User accuracy (%)	80.8	96.5	81.5	68.6	
Overall accuracy (%)	79.9				
Kappa coefficient	0.73				
SVM					
Single rain-fed rice	301	0	65	134	500
Double irrigated rice	0	470	18	12	500
Double rain-fed rice	31	5	446	18	500
Triple irrigated rice	0	6	9	485	500
Total	332	481	538	649	2,000
Producer accuracy (%)	60.2	94.0	89.2	97.0	
User accuracy (%)	90.7	97.7	82.9	74.7	
Overall accuracy (%)	85.1				
Kappa coefficient	0.80				

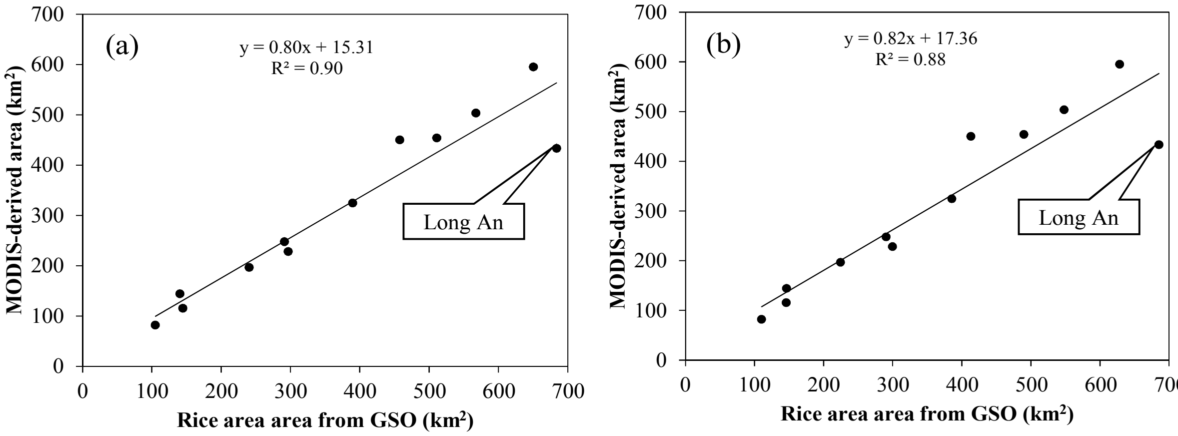

Figure 3. Results of regression analysis between MODIS-derived rice area and rice area statistics. The MODIS-derived rice areas were derived from the classification results using: (a) LMM, and (b) SVM.

4. CONCLUSIONS

The application of LMM and SVM to the filtered NDVI data confirmed the validity of these methods for quantifying rice cropping systems on a regional scale. The comparison results showed that SVM gave slightly better classification results than LMM. The overall accuracy and Kappa coefficient achieved by LMM were 79.9% and 0.73, and those by SVM were 85.1% and 0.8, respectively. However, there was no statistically significant difference in classification accuracy between these two methods (Z-test = 0.275). The comparison between the classification results and rice statistics reaffirmed good agreement at the provincial level ($R^2 > 0.8$). The methods used in this study could be applied to other regions for crop monitoring purposes.

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