RICE MONITORING IN THE MEKONG DELTA, VIETNAM

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Abstract: Vietnam is one of the world's largest rice exporting countries since the mid-1990s and the fifth producer country in the world of the global production. Of which, the fertile Mekong Delta at the southern tip of Vietnam accounts for more than half of the rice production. In addition, the Vietnamese are among the world top five rice consumers. This makes the rice growing areas of the Mekong Delta a good test region to assess the rice monitoring system using remote sensing techniques. However, the country located in the tropics, it is often clouded to affect the image quality obtained from optical remote sensors. Radar remote sensing overcomes this drawback and can acquire images at any time of year.

The paper presents research results of rice monitoring using various kinds of SAR data acquired at different years, i.e. ERS2-SAR (1997), ENVISAT-ASAR (2007) and TerraSAR-X (2010-2011) in An Giang, Can Tho and Soc Trang provinces of the Mekong Delta, which has a very complex cropping system (single, double, and even triple rice crops per year). The yield predictive model based on multiple regression analysis was proposed and attained good results, and thus proved to be a potential tool for monitoring rice crops in the study area.

INTRODUCTION

Rice (*Oryza sativa*) is one of the world's major agricultural crops and is the staple food for more than half of the world population. Food security has become a key global issue due to the Asian region's rapid population growth, extensive conversion of arable lands, and declining overall productivity in some areas because of climate effects (floods, water shortage, low or high temperature) and plant diseases. To maintain a close balance between rice production and food demand, effective rice monitoring programs are necessary at regional, national and global levels. In particular, there is a need to develop spatio-temporal monitoring system that can accurately assess rice cultivated area, crop vigour and health, and can predict crop yield.

Traditionally, estimates of rice planting area and productivity are based on ground survey data. It is often time-consuming and expensive. In the early 1980s, much attention was paid to using optical remote sensing for crop yield estimation all over the world. Remarkable achievements were obtained after many studies were carried out (Li et al., 2003). Nevertheless, because of the limitations of the data acquisition for optical remote sensing, it was very difficult to carry out real-time monitoring of crop growth and estimate rice yield promptly based on these methods. Hence, radar remote sensing is the obvious choice as the most appropriate data source for agricultural monitoring and crop yield estimating in large areas in the tropical and sub-tropical regions (Chen et al., 2006; Li et al., 2003; Ribbes and Le-Toan, 1999).

Changes in rice cultivation systems have been observed in various countries of the world in recent years, especially in the Mekong Delta. The changes in cultural practices have impacts on remote sensing methods developed for rice monitoring, in particular, methods using radar data. This paper presents results of research studies on the use of radar remote sensing data to estimate the yield based on agro-meteorological model using ERS2-SAR (Lam-Dao et al., 2006), and statistical model (multiple linear regression analysis) using ENVISAT-ASAR APP (Lam-Dao, 2009) and TerraSAR-X StripMap (TSX SM) images (Lam-Dao et al., 2012).

METHODS

Study area and data used

ERS2-SAR (1997) in Soc Trang, ENVISAT-ASAR (2007) in An Giang, and TerraSAR-X (2010-2011) in An Giang and Can Tho provinces of the Mekong Delta were acquired for rice monitoring purposes (Figure 1).

Figure 1: Map of study areas (Source: http://gis.chinhphu.vn/)

ERS-2 SAR PRI data of C-band (track 75 and frame 3411), VV polarisation, 30 m spatial resolution, at 35-day repeat intervals were acquired from August to November 1997 for the study area in Soc Trang province.

The Envisat ASAR APP data of C-band, HH&VV polarisation, IS2 incidence angle (19.2^o - 26.7^o), and ascending mode were available for An Giang province at the months from January to July of the year 2007. APP images have a nominal spatial resolution of 30 m x 30 m and pixel size of 12.5 m x 12.5 m with a swath width of about 100 km.

The TerraSAR-X time series data of X-band that was used in the study sites of An Giang and Can Tho with StripMap mode, HH&VV polarisation, incidence angle of 34.9^o – 36.5^o, and ascending mode was available during Autumn-Winter (AW) 2010 crop season for An Giang site and Winter-Spring (WS) 2011 for Can Tho. TerraSAR-X images have high spatial resolution of 3 m with a swath width of about 30 km, and a revisit interval of 11 days.

Methods

A methodology for rice yield estimation based on agro-meteorological model has been developed by Ribbes and Le-Toan (1999). The approach consists in coupling ERS-SAR data and the ORYZA rice production model in order to simulate plant growth and thus the final yield. Seeding date and plant biomass as a function of time are key parameters that can both be retrieved from SAR data and are necessary inputs to production models. In order to estimate the rice yield of a field, the following operations in RISAR processing (Matra Systems and Information,

2000) are performed: i. Calculate the radar backscattering coefficient of the selected rice fields within the ERS-SAR images; ii. Retrieve, from ERS-SAR data, plant parameters necessary to parameterize the rice growth model; iii. Simulate rice growth using ORYZA model parameterized with input data retrieved from SAR data and climatic data. The rice fields were selected using the vector cover in RISAR. These fields represented the various rice cropping systems. The total irradiance was not available; therefore it was calculated from the average irradiance multiplied by day light of 11 hours (maximum sunshine hours during the time of May 1997 – April 1998 measured at Can Tho gauge station).

Rice yield estimation based on statistical model: By using multiple linear regression analysis, the correlation between backscattering coefficients σ^o of multi-date SAR images acquired during the crop season and the *in situ* measured yield was derived. The distribution maps of estimated rice yield were then produced on the basis of that relationship. Consequently, rice production was finally estimated on the basis of these yield maps and rice/non-rice maps (Figure 2).

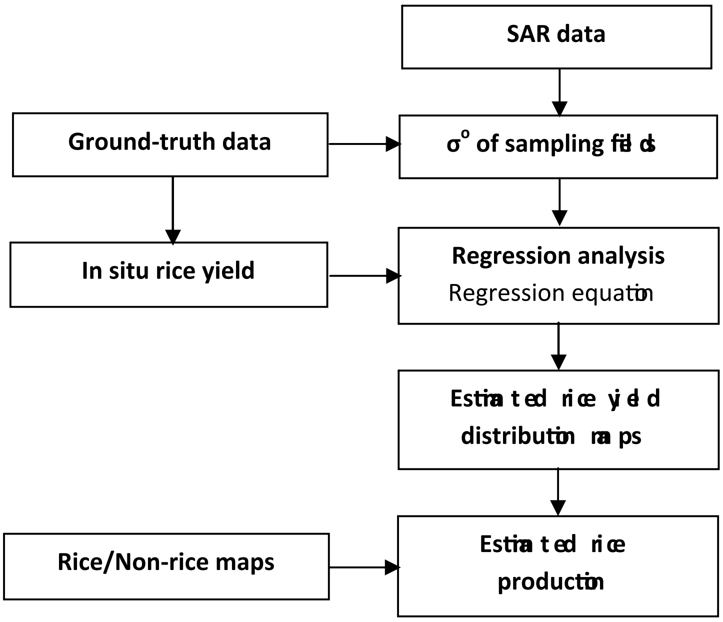


Figure 2: Methods used for estimating rice production (Lam-Dao, 2009)

Rice parameters such as rice yield and sowing date of the sampling fields were collected with different seed varieties ranging from 95 to 105-day cycle. The method of multiple linear regression analyses between *in situ* measured yield and the backscatter coefficient of multi-temporal SAR images was used. To estimate the yield, at least three-date radar data of dual polarisation in the crop is needed.

RESULTS AND DISCUSSION

Agro-meteorological model of rice yield estimation

Case study of ERS2-SAR data used

The sowing date and crop cycle length were deduced on the basis of the temporal change of backscattering coefficient (Figure 3) and the growth cycle of rice cropping systems and were assigned into the model, because the ground data was not available during the acquisition time of ERS-SAR images. The growth cycle of rice cropping systems was deduced based on the behavior of σ^o of 74 homogeneous rice sampling boxes, which were selected on the calibrated-registered images and extracted for various rice cropping systems such as single-, double- or triple-crop rice. The box size of 14x14 pixels was chosen to attain a 90% confidence level for radiometric resolution bounds of +/-0.5 dB (Laur et al., 2002).

As an example, a rice field P1H1_1 located in Ke Sach of Soc Trang province was represented for triple-crop rice fields. The estimated rice yield result of Summer-Autumn (SA) crop in 1997 was 4,432 kg/ha. It is noted that the statistical average yield of SA crop in 1998 was 4,802 kg/ha for Ke Sach district.

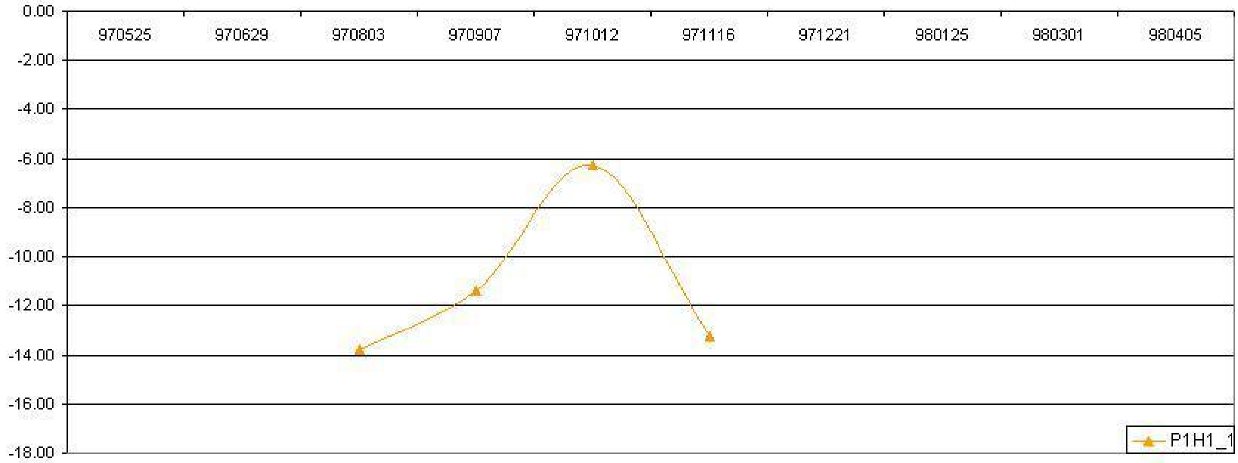


Figure 3: Temporal variation of σ^o of SA crop in 1997 on triple-crop rice fields

Statistical model of rice yield estimation

Case study of Enivsat-ASAR data used

Since HH, VV and polarisation ratio HH/VV at each of the acquisition dates were not strongly related to biomass (hence to the yield), multi-temporal values of these measurements were explored. In order to derive the relationship for predicting the rice yield by district, multiple linear regression analysis of the yield as function of the backscattering coefficients (HH, VV and HH/VV) at 3 dates for WS and SA 2007 crops was performed. The coefficients of determination between the in situ measured yield of ten sampling fields and their radar measurements were significantly high, except in one case (VV, SA crop), and polarisation ratios were higher than that between yield and HH or VV (Table 1).

Table 1: Correlation between sample rice yield and HH, VV, HH/VV by rice crop (n=10).

Rice crop	**r^2**		
	HH	**VV**	**HH/VV**
WS 2007	0.575	0.661	0.675
SA 2007	0.653	0.328	0.833

The regression equations between rice yield and polarisation ratios of sampling fields at Cho Moi district of An Giang province in WS and SA 2007 crops using LINEST function were determined as follows (1, 2):

WS crop:
$$Y_{Ra} = -0.033\ Ra_1 + 0.017\ Ra_2 + 0.019\ Ra_3 + 0.628 \quad (1)$$
$$r^2 = 0.675,\ se_y = 0.38 \text{ ton/ha}$$

SA crop:
$$Y_{Ra} = 0.072\ Ra_1 - 0.017\ Ra_2 - 0.002\ Ra_3 + 0.503 \quad (2)$$
$$r^2 = 0.833,\ se_y = 0.11 \text{ ton/ha}$$

where:

Y_{Ra} : rice yield (kg/m^2),
Ra_1 : polarisation ratio of first date image,
Ra_2 : polarisation ratio of second date image,
Ra_3 : polarisation ratio of third date image,
r^2 : the coefficient of determination,
se_y : the standard error for the y estimate.

In the case of WS and SA crops, the values of r^2 were 0.675 and 0.833, and se_y were 0.38 and 0.11 ton/ha, respectively. It indicates that the relationship is stronger in SA than in WS crop season of the Cho Moi district.

The detected rice fields were classified into 17 yield levels, ranging from 0.5 to 10 ton/ha through analysis of the relationship between rice yield and backscattering coefficients of three-date ASAR APP images acquired over the rice growing period.

The yield of rice fields planted in SA 2007 crop at Cho Moi district was estimated on the basis of the correlation between in situ rice yield and polarisation ratios (Equation 2). The rice fields with estimated yield levels ranging from four to six ton per hectare were dominant and occupied 89.8% total of rice area planted in this crop season, whereas the statistical average yield of rice in the same crop at the district was 4.86 ton/ha (AGSO, 2008).

Consequently, there was a good agreement between rice production estimated from ASAR APP and the official statistics with the difference of 3.2% between them (Table 5). This accuracy of yield estimation was higher than those reported in the previous studies (e.g. Ribbes and Le-Toan ,1999; Li et al., 2003; Chen and Mcnairn, 2006).

In the case of WS 2007 crop, using regression equation (Equation 1) rice production was estimated. About 80% of total rice area planted had the estimated yield from 4.5 to 8 ton/ha, whereas the statistical mean yield of the district was 7.36 ton/ha. Consequently, the rice production in WS 2007 crop of Cho Moi district was underestimated, i.e. 19.4% lower than the agency statistics (Table 2).

Table 2: Percentage error between rice production in WS and SA 2007 crops at Cho Moi district derived from three-date polarisation ratio data and statistical data.

Rice crop	Statistical data (Ton)	Estimated Production (Ton)	Percentage error (%)
WS 2007	131595	106128	-19.4
SA 2007	79256	81820	3.2

A distribution map of estimated yield of the rice fields planted in SA 2007 crop at Cho Moi district using three-date polarisation ratios and LINEST regression analysis was plotted (Figure 4). Most of the rice fields with yield ranging from four to six ton /ha were distributed throughout the district.

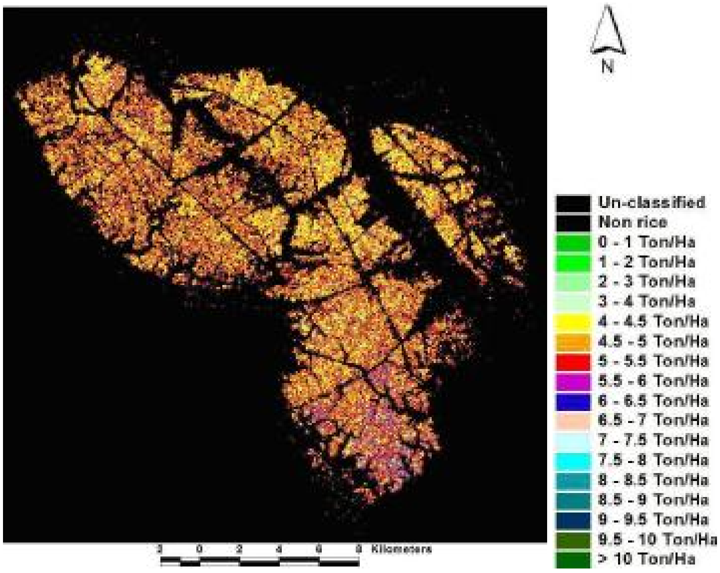


Figure 4: A distribution map of estimated rice yield in SA 2007 crop at Cho Moi district using three-date polarisation ratio and LINEST regression analysis.

The results of the above analysis using a linear regression equation proved that the statistical model-based method worked very well in the case of SA 2007 crop at Cho Moi district where the relationship between in situ yield point data and polarisation ratio data was positive with the high correlation coefficient of 0.913.

Case study of TerraSAR-X data used

In order to derive the relationship between rice yield and the polarisation ratios of multi-temporal TSX SM images for yield estimation, analysis of multiple linear regressions was performed for the study sites of An Giang with five-date data acquired and Can Tho city with four-date data used.

An Giang Case

In the case of three-date radar data used, the images should be acquired during the three growing stages of rice (vegetative, reproductive and ripening stages). As in the cases 7, 8, 11 and 12, coefficients of determination of the HH/VV ratios are higher than that in the case with absence of image acquired in the middle of the crop (such as the cases 13, 14, 15, and 16). In the cases of the images collected during the early and mid crop or mid and late rice crop, their coefficients of determination are higher than that of the cases that absence image acquired in the mid crop (Table 3).

To estimate rice yield by using combinations of four or five-date data, that needs to be acquired in the three rice growing stages or in two first stages or two final stages. As in the case six, no radar images during the mid crop, a coefficient of determination is lower than that of the remaining cases. If more than three radar images are selected for multiple linear regression analysis, then the coefficient of determination is higher. Results of regression analysis of HH/VV pointed out that with three-date data distributed at the three stages (in the case 7 and 8) used also gives the coefficient of determination almost the same to the case of more than three used (Table 3).

Table 3: Correlation between HH/VV ratio and sample rice yield in AW 2010 crop of Cho Moi district

Case	Image combination	r^2
1	1, 2, 3, 4, 5	0.795
2	2, 3, 4, 5	0.795
3	1, 2, 3, 5	0.781
4	1, 3, 4, 5	0.779
5	1, 2, 3, 4	0.681
6	1, 2, 4, 5	0.494
7	2, 3, 5	0.781
8	1, 3, 5	0.765
9	3, 4, 5	0.754
10	1, 2, 3	0.659
11	1, 3, 4	0.623
12	2, 3, 4	0.614
13	1, 2, 5	0.494
14	2, 4, 5	0.401
15	1, 4, 5	0.379
16	1, 2, 4	0.088

In this paper, the rice yield was estimated for the cases 1 and 7 using five and three-date TSX SM data, respectively. Regression equations between in situ measured rice yield and polarisation ratios for case 1 and 7 in AW 2010 crop at Cho Moi district were formulated as follows (3, 4):

$$Y_{Ra} = 0.0008*Ra_1 - 0.0414*Ra_2 + 0.0071*Ra_3 - 0.0009*Ra_4 + 0.0930*Ra_5 + 0.4949 \quad (3)$$

$$r^2 = 0.795,\ se_y = 0.18 \text{ ton/ha}$$

$$Y_{Ra} = -0.0422*Ra_1 + 0.0068*Ra_2 + 0.0969*Ra_3 + 0.4918 \quad (4)$$

$$r^2 = 0.781,\ se_y = 0.16 \text{ ton/ha}$$

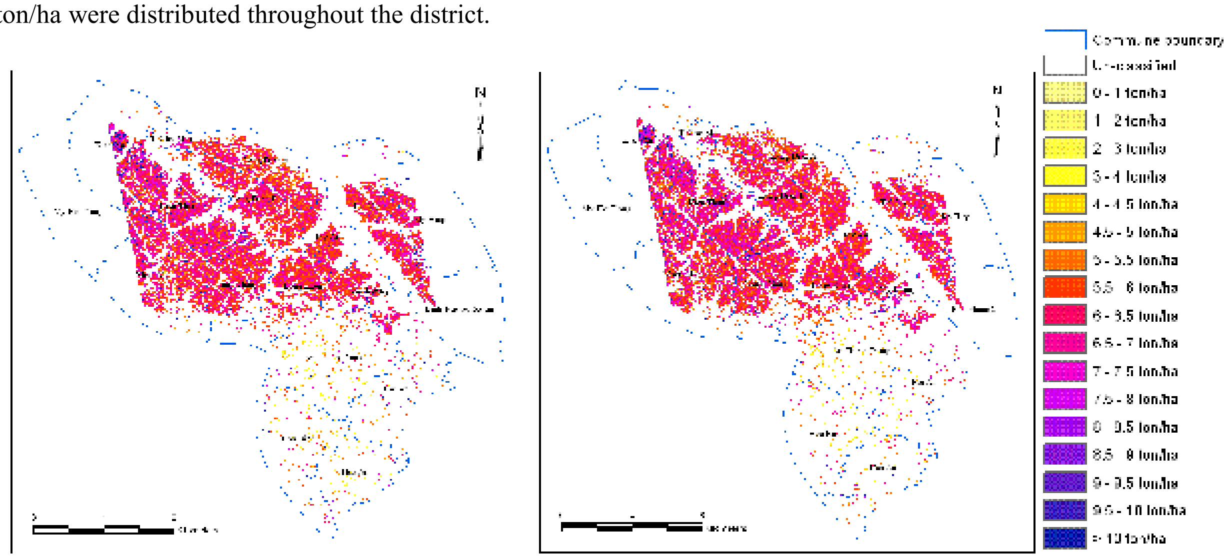
Where:

Y_{Ra} : estimated rice yield (kg/m^2),
Ra_1 : polarisation ratio of first date image,
Ra_2 : polarisation ratio of second date image,
Ra_3 : polarisation ratio of third date image,
Ra_4 : polarisation ratio of fourth date image,
Ra_5 : polarisation ratio of fifth date image,
r^2 : the coefficient of determination,
se_y : the standard error for the y estimate.

The coefficient of determination and the standard error for the rice yield estimate in the case 1 and 7 were 0.795, 0.781; and 0.18, 0.16 ton/ha, respectively. It indicates that the relationship is positive and can be consequently used to predict the yield for all rice fields planted in AW 2010 crop season at the Cho Moi district.

The yield of rice fields was estimated on the basis of the correlation between *in situ* rice yield and polarisation ratios (Equation 3, 4) and classified into 17 yield levels, ranging from 0.5 to 10 ton/ha. The rice fields with estimated yield levels ranging from 5 to 7.5 ton per hectare were dominant and occupied 87.5% and 87.2% total of rice area planted in this crop season for the case 1 and 7, respectively.

Distribution maps of estimated yield of the rice fields planted in AW 2010 crop at Cho Moi district using five-date and three-date polarisation ratios were plotted (Figure 5). Most of the rice fields with yield ranging from 5 to 7.5 ton/ha were distributed throughout the district.



a) b)

Figure 5: The distribution maps of estimated rice yield in AW 2010 crop at Cho Moi district using five-date (a) and three-date (b) polarisation ratio data

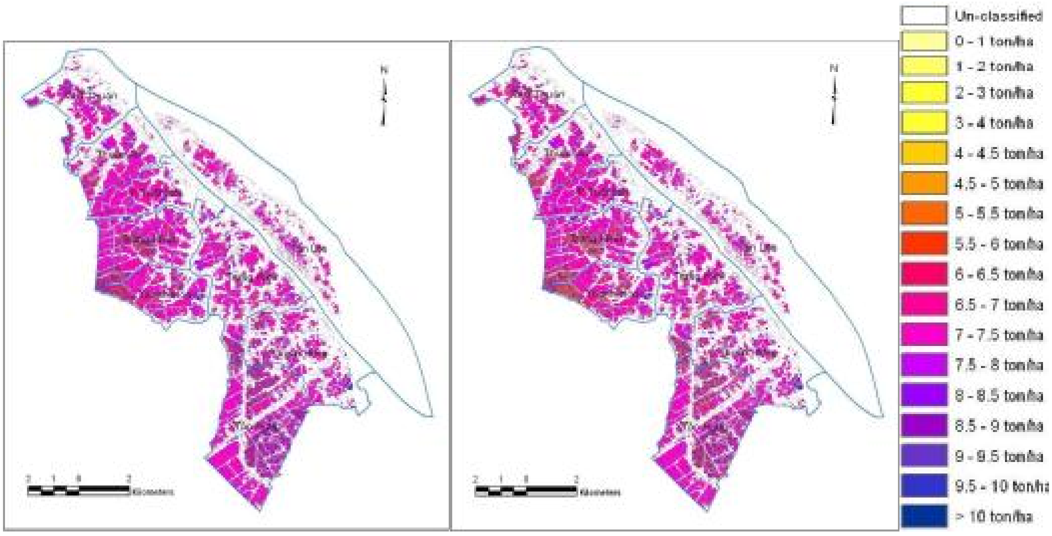
The results of rice production by commune in the AW 2010 crop estimated from TSX SM images were compared with the statistics of the Division of Agriculture and Rural Development of Cho Moi district. Communes of Cho Moi such as Kien An, My Hoi Dong, Nhon My, My Hiep and Binh Phuoc Xuan could not be compared, because the radar images do not cover all their area. Several other communes (An Thanh Trung, Hoa Binh, Hoa An, Hoi An) in the southern part planted earlier or did not planted rice in the AW crop. Consequently, only the rest communes of Cho Moi are analysed and proved a good agreement between rice production estimated from TSX SM data and the official statistics with the difference of -5.3 % (case 1) and -5.0 % (case 7) between them (Table 4).

Table 4: Percentage error between rice production by commune in AW 2010 crop at Cho Moi district derived from polarisation ratio data and statistical data

Commune name	Statistical data (Ton)	4-date polarisation ratio data used		3-date polarisation ratio data used	
		Estimated production (Ton)	Percentage error (%)	Estimated production (Ton)	Percentage error (%)
Long Kien	5880	4215	-28.3	4214	-28.3
My Luong town	2204	2069	-6.1	2081	-5.6
Long Giang	5940	5968	0.5	5992	0.9
My An	1659	2449	47.6	2461	48.3
Kien Thanh	7800	7297	-6.5	7331	-6.0
Long Dien B	5490	5832	6.2	5820	6.0
Tan My	4680	4493	-4.0	4521	-3.4
Long Dien A	5292	4662	-11.9	4655	-12.0
Cho Moi town	342	228	-33.3	229	-33.0
Total	**39287**	**37212**	**-5.3**	**37303**	**-5.0**

The results of the above analysis using the multiple linear regression equation proved that the statistical model-based method worked very well in the case of AW 2010 crop at Cho Moi district where the relationship between in situ yield point data and polarisation ratio data was positive with the high correlation coefficient of 0.892 in case 1 and 0.884 in case 7. However, at communes of Long Kien, My An and Cho Moi town errors are higher than the others could be due to administrative boundary layer used in this study is not coincided.

Can Tho Case



a) b)

Figure 6: The distribution maps of estimated rice yield in WS 2011 crop at Thot Not district using four-date (a) and three-date (b) polarisation ratio data

In this case, the results of rice production by commune in the WS 2011 crop estimated from TSX SM images were compared with the statistics of the Division of Agriculture and Rural Development of Thot Not district, Can Tho city. The percentage errors between rice production estimated from TSX SM data and the official statistics are -21.4% and -19.9 % for four- and three-date data used, respectively (Table 5).

Table 5: Percentage error between rice production by commune in WS 2011 crop at Thot Not district derived from polarisation ratio data and statistical data

Commune name	Statistical data (Ton)	4-date polarisation ratio data used		3-date polarisation ratio data used	
		Estimated production (Ton)	Percentage error (%)	Estimated production (Ton)	Percentage error (%)
Tan Hung	8660	6905	-20.3	6730	-22.3
Thanh Hoa	4146	3266	-21.2	3180	-23.3
Trung Nhut	6477	4414	-31.8	4308	-33.5
Trung Kien	5461	4598	-15.8	4541	-16.8
Thot Not town	2213	2453	10.9	2455	11.0
Thuan An	2628	2341	-10.9	2305	-12.3
Thoi Thuan	2978	2113	-29.0	2061	-30.8
Total	**32562**	**26090**	**-19.9**	**25581**	**-21.4**

CONCLUSIONS & RECOMMENDATIONS

Result of predicted rice yield of the Summer-Autumn 1997 crop based on agro-meteorological model in the study site of Soc Trang was reasonable. But it is necessary to have ground data for accuracy assessment of estimated rice yields.

The statistical model-based method for rice yield estimation, based on the relationship between the in situ measured yield and polarisation ratios extracted from the three-date ASAR APP images taken during the crop growth was established from the multiple regression analysis. Then, pixel-based rice yield was estimated on the basis of this relationship, and the production of rice area was finally computed. The method provides good results in Cho Moi district in 2007. This method worked very well in the same district for 2010 where the relationship between in situ measured yield point data and polarisation ratio data derived from multi-date TerraSAR-X StripMap images was positive with the high correlation coefficient. Research results showed that there is the higher correlation between *in situ* rice yield and polarisation ratio data, when more polarisation ratio data is used for regression analysis and one of these ratio data must be collected in the middle of the rice crop. The study also pointed out that at least three-date data of TerraSAR-X StripMap can be used to estimate the rice yield.

Further research should be carried out to improve and validate the statistical model-based method for predicting rice production using dual polarisation SAR data and deploy for other regions of the Mekong Delta, Vietnam.

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