DISCRIMINATING AND MAPPING RICE ECOSYSTEMS IN CENTRAL LUZON PHILIPPINES USING ENVISAT ASAR IMAGES

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ABSTRACT: Monitoring rice crop systems in the Philippines is essential in ensuring food security for the country. ENVISAT ASAR images offer an effective alternative to conventional methods of rice monitoring because of its all-weather imaging capability. This study determine the suitable approach in mapping irrigated and rainfed rice areas using multi-temporal ENVISAT ASAR images for two cropping seasons in Central Luzon, Philippines to update the land-use paper maps and to promote transfer of location-specific technologies, farm management and cropping system. Five ASAR Alternating Polarization Precision (APP) images and eleven ASAR Image Mode (IM) images were acquired during the dry cropping season (01/01/10, 02/05/10, and 04/16/10) and wet cropping season (05/23/10, 06/11/10, 06/27/10, 08/01/10, 08/20/10 and 09/05/10), respectively. Image pre-processing and calculation of radar backscatter coefficient of the images were performed. Supervised classification techniques were applied to the color composite images. Rice area estimation, accuracy assessment, and comparison of rice area produced from the classified images with the government reported statistics were conducted. The method delineated rice production areas for one wet and one dry season, and was able to extract trend on rice cultivation as a function of different planting dates. A classification accuracy of 82% and 92% was achieved for dry and wet season, respectively. The ASAR-derived rice area estimates were highly comparable to the government reported statistics with range of percentage of rice field mapped of 94 to 106%. Image subtraction and GIS analysis were applied to the classified image of dry and wet season to produce the map of irrigated and rainfed rice areas.

1. INTRODUCTION

Rice (Oryza sativa) is the primary food source for most Filipinos affecting the economic, cultural and nutritional aspects of the country making this crop's successful annual production of key significance (Chen and McNairn, 2005). The average total rice utilization in the Philippines computed from 2000 to 2010 statistics increases by 433,000 metric tons per year while the domestic rice production only increases by 291,000 metric tons per year. Despite yield improvements through the use of high yielding varieties, rice cropping technologies and expansion of irrigable areas to increase rice production, food security in the country is still an issue as depicted by the spiraling price of rice. For instances in 2008, a sudden increase of the price of rice from ₱22 to ₱30 in the local market as a result of rice hoarding occurred. This problem could be avoided when there is a scheme of monitoring, estimating and forecasting agricultural production for local and central planning in the country.

The goal of crop production forecasting is to estimate areas of paddy fields (Cheng et. al., 2004). The conventional method of rice monitoring involves ground surveys conducted by Bureau of Agricultural Statistics (BAS) every semester to estimate the rice acreage and production at the provincial and national level. It has been quite difficult for this method to obtain timely and accurate rice area data (Jiao et. al., 2006: Le et. al., 2008). All-weather radar satellite offers an effective alternative to conventional method since optical satellite data is hampered by poor weather conditions especially in the tropics like the Philippines. The actual condition on rice crop, its distribution and acreage assessment can be accurately mapped based on temporal variation in radar backscatter (Aschbacher et al., 1995: Brisco & Brown, 1998: Kurosu and Fujita, 1997: Ribbles and Le Toan, 1999: Inoue et. al., 2002: and Liew et. al., 1998).

Rice ecosystem in the country is classified as irrigated or rainfed based on the major source of water supply. In irrigated rice fields, water is supplied artificially from a surface or underground source. Two to three cropping of rice per year can be grown depending on water availability. On the other hand, rainfed rice fields are irrigated by rainfall, sometimes supplemented by localized runoff collection. One cropping per year is practiced, followed and preceded by a secondary crop like corn or vegetables. Many studies conducted in the past on the use of remote sensing in rice monitoring focus in mapping either one of this type since these ecosystems varies in terms of source of irrigation, cropping pattern, planting dates, variety and management aspects. These variations complicate the use of SAR imagery for mapping rice fields. The primary goal of this study is to develop a technique to map irrigated and rainfed rice areas using multi-temporal SAR images for two cropping seasons in Central Luzon. Discrimination of these ecosystems helps in proper transfer of location-specific technologies, farm management and cropping systems.

2. STUDY AREA

Two provinces in the Philippines were used to develop and test the methodologies, the provinces of Nueva Ecija and Pangasinan (figure 1). Nueve Ecija has an approximately 186,556 hectares of which 123,883 hectares is irrigated and 60,723 hectares is rainfed. It has two pronounced seasons: dry from December to April and wet from June to September with monthly rainfall around 30 millimeters and 370 millimeters, respectively. On the other hand, Pangasinan has an approximately 185,962 hectares of which 78,052 hectares irrigated, 90,592 hectares rainfed and 8,417 hectares upland. The wet season starts from May to October and dry season starts from November to April. During the dry season, rainfall is minimal and there are very few typhoons. The wet season is characterized by frequent rain showers and typhoons. The fields are flooded for most of the season.

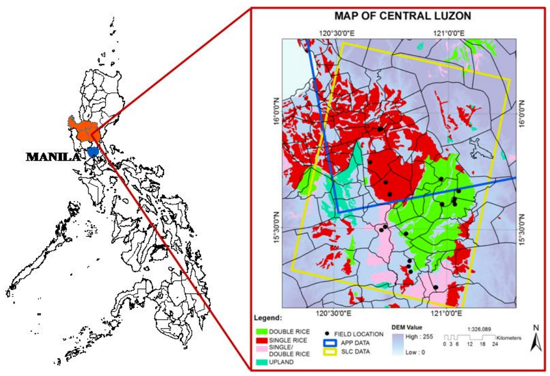

Figure 1. Location map of the study area.

3. METHODOLOGY

Figure 2 shows the detailed schematic diagram of the approach used for mapping rice ecosystem. The ENVISAT ASAR data were co-registered, multilooked, filtered using Enhanced Lee and geocoded to produce a calibrated backscatter coefficient of each of the images. For the dry season, one color composite image of the multi-temporal images was created for classification. For wet season, four color composite images were produced using the images from three succeeding dates from the six datasets available. Maximum likelihood classification (MLC) and support vector machine (SVM) were applied on each of the multi-temporal images. Rice area estimation and accuracy assessment of the classified images were performed. Image subtraction and GIS analysis were conducted on the classified images from dry and wet seasons assuming that the rice area derived from the dry season represents the irrigated rice while the rice area derived from the wet season represents the irrigated and rainfed rice. The final map produced shows the extent and distribution of irrigated and rainfed rice areas. The ASAR-derived rice area was then compared to area harvested from the government reported statistics.

The measures of accuracy used are classification accuracy, rice location accuracy, rice area accuracy and percentage of rice field mapped. Overall accuracy and kappa coefficient for each classified images were calculated to describe the accuracy of the classified image with respect to the ground truth ROIs. Rice location accuracy is computed as the number of correctly classified rice ground points divided by the total rice ground points. Rice area accuracy is the ratio of the number of pixels classified as rice and the total number of pixels used contained within the known polygon of rice. Percentage of rice field mapped is the ratios of rice acreage to total acreage, for both the government and classification estimates.

3.1 Field Data Collection

The study covered two rice cropping seasons in 2010. The dry season covered January to April 2010 and the wet season May to September 2010. During the dry season, four field surveys which are consistent with image acquisition were conducted to describe the general physical characteristics, the management strategies applied, the crop variety, and crop growth stages of the study area. During the wet season, no field survey was conducted since the images were derived from Philippine Rice Research Institute (PhilRice) and no corresponding ground survey was conducted by the agency. Therefore, the validation points used were taken from the 2008 wet season rice production data from PhilRice in which the datasets served as reference for the validation points in image classification assuming that the cropping calendar during the 2008 and 2010 wet season were the same.

3.2 ENVISAT ASAR Data

A total of sixteen images were used in this study. Five ENVISAT ASAR Alternating Polarization Precision (APP) level 1B images taken on three dates during 2010 dry season were acquired from the European Space Agency. APP is multi-look, ground range images and non-geolocated with minimal geometrical corrections. Eleven ENVISAT ASAR Image Mode Single Look Complex images taken on five dates during the 2010 wet season were taken from PhilRice. The dates of acquisition of the images were determined based on the onset of rainfall and on the critical stages of rice growth, which is essential to rice area mapping. Specifically the images were taken during flooding (January 1, 2010), vegetative (February 5, 2010) and maturity stage (April 16, 2010) for the dry season images. For wet season datasets, the images were taken during flooding (May 23, 2010), vegetative (June 11 & 27, 2010), early reproductive (August 1, 2010), reproductive (August 20, 2010) and maturity stage (September 5, 2010).

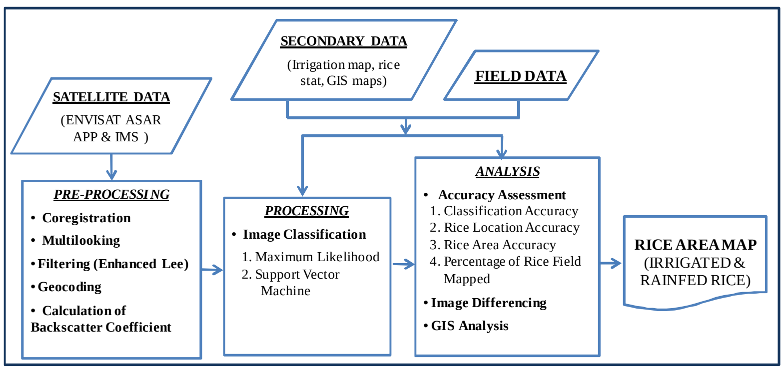

Figure 2. Flowchart of the methodology used for rice area mapping using ENVISAT ASAR images.

4. RESULTS AND DISCUSSION

4.1 Rice Temporal Cultivation Pattern Based on ASAR Images

Since farmers do not plant their rice crop at the same time, the delineation of rice fields cultivated at different times during a rice production season is a challenge. In this study, rice cultivation was categorized as early stage, middle stage and late stage rice based on crop calendar. Results showed that the use of multi-temporal ASAR images (figure 3) could determined the cultivation pattern of the different stages of rice as a result of differences in planting dates (figure 4) provided that the dates of acquisition of the images capture the complete growth cycle of rice starting from flooding to harvest. The information on cultivation date is important in determining the farmers' practices in the area for an effective transfer of technology. Likewise, information on cultivation is a prerequisite for rice yield prediction.

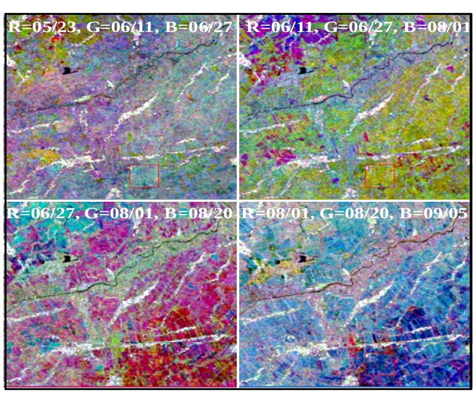

Figure 3. Multi-temporal color composite of three ENVISAT ASAR images.

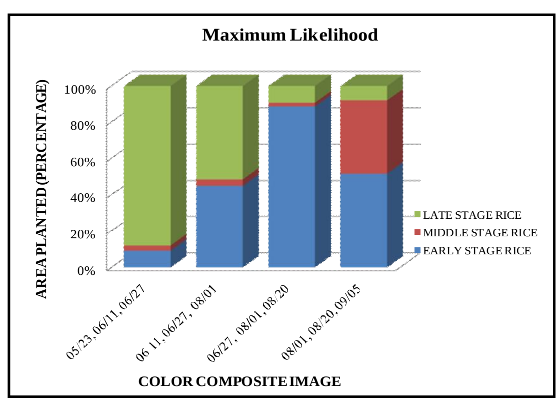

Figure 4. Pattern of rice cultivation in the study area.

4.2 Rice Field Mapping

One color composite image for dry season and four color composite images for wet season were classified using MLC and SVM methods. The application of MLC with Enhanced Lee filter to color composite image 01/01, 02/05, 04/16 gave the highest accuracy of 82% during the dry season. For the wet season, the color composite image of June 27, August 1 and August 20 with Enhanced Lee filter and SVM (Polynomial) with 91% classification accuracy consistently demonstrated high accuracies on four measure of accuracies used (table 1).

Table 2 compares the statistics derived from the integrated mapping approach to the government statistics reported for both Nueva Ecija and Pangasinan. The ratio of rice acreage to total acreage, for both the government and classification estimates, is compared in this table. For the dry season, the SVM methods and MLC produced very comparable results to within 5% and 6% of the government reported data for Nueva Ecija and Pangasinan, respectively. However, the methods also overestimated and underestimated the rice acreage (relative to the total acreage). For wet season, the MLC method applied to color composite image of 06/11, 06/27, 08/01 and 06/27, 08/01, 08/20 with Enhanced Lee filter were highly comparable to the government reported statistics to within 3%.

Table 1. Accuracy of rice field mapping using the classification methods used.

CLASSIFIED IMAGE	*CLASSIFICATION ACCURACY*	*RICE LOCATION ACCURACY*	*RICE AREA ACCURACY*
DRY SEASON			
ENHANCED LEE FILTER			
01/01, 02/05, 04/16 MLC	82.14%	65.12%	78.43%
01/01, 02/05, 04/16 SVM Polynomial	79.02%	53.49%	72.00%
01/01, 02/05, 04/16 SVM Radial	77.68%	51.16%	63.64%
NO FILTER			
01/01, 02/05, 04/16 MLC	62.95%	65.12%	73.17%
01/01, 02/05, 04/16 SVM Polynomial	63.39%	23.26%	37.50%
01/01, 02/05, 04/16 SVM Radial	62.50%	25.58%	37.50%
WET SEASON			
ENHANCED LEE FILTER			
05/23, 06/11, 06/27 MLC	***86.66%***	77.08%	76.92%
05/23, 06/11, 06/27 SVM Polynomial	***86.80%***	76.04%	***85.54%***
05/23, 06/11, 06/27 SVM Radial	***86.07%***	76.04%	***87.10%***
06/11, 06/27, 08/01 MLC	***87.54%***	66.67%	75.35%
06/11, 06/27, 08/01 SVM Polynomial	84.46%	79.17%	77.56%
06/11, 06/27, 08/01 SVM Radial	***85.34%***	77.08%	73.37%
06/27, 08/01, 08/20 MLC	***91.79%***	75.00%	83.23%
06/27, 08/01, 08/20 SVM Polynomial	***90.62%***	***85.42%***	***86.78%***
06/27, 08/01, 08/20 SVM Radial	***91.64%***	83.33%	81.11%
08/01, 08/20, 09/05 MLC	77.13%	83.33%	***97.04%***
08/01, 08/20, 09/05 SVM Polynomial	73.17%	***86.46%***	***94.51%***
08/01, 08/20, 09/05 SVM Radial	74.19%	***86.46%***	***94.51%***
NO FILTER			
05/23, 06/11, 06/27 MLC	80.35%	79.17%	81.97%
05/23, 06/11, 06/27 SVM Polynomial	80.65%	82.29%	82.86%
05/23, 06/11, 06/27 SVM Radial	80.21%	82.29%	82.86%
06/11, 06/27, 08/01 MLC	80.06%	65.63%	72.60%
06/11, 06/27, 08/01 SVM Polynomial	78.74%	83.33%	84.40%
06/11, 06/27, 08/01 SVM Radial	79.33%	83.33%	79.33%
06/27, 08/01, 08/20 MLC	81.09%	66.67%	73.94%
06/27, 08/01, 08/20 SVM Polynomial	81.82%	***87.50%***	***86.08%***
06/27, 08/01, 08/20 SVM Radial	82.26%	***87.50%***	***86.08%***
08/01, 08/20, 09/05 MLC	69.21%	73.96%	***86.59%***
08/01, 08/20, 09/05 SVM Polynomial	69.06%	***86.46%***	***92.02%***
08/01, 08/20, 09/05 SVM Radial	68.77%	***87.50%***	***88.33%***

Table 2. Accuracy of rice field mapping compared to government reported statistics.

CLASSIFIED IMAGE	*DA & LGU* Total Land Area A	Area Harvested B	*SAR IMAGE* Total Land Area C	Total Rice Area D	**% Rice Field Mapped** (A/B)/(C/D)
DRY SEASON					
ENHANCED LEE FILTER					
Pangasinan					
01/01, 02/05, 04/16 MLC	144577	78348	147764	59975	***75%***
01/01, 02/05, 04/16 SVM Polynomial	144577	78348	147764	38460	***48%***
01/01, 02/05, 04/16 SVM Radial	144577	78348	147764	36306	***45%***
Nueva Ecija					
01/01, 02/05, 04/16 MLC	172042	33652	172043	55163	***164%***
01/01, 02/05, 04/16 SVM Polynomial	172042	33652	172043	34460	***102%***
01/01, 02/05, 04/16 SVM Radial	172042	33652	172043	31978	***95%***
NO FILTER					
Pangasinan					
01/01, 02/05, 04/16 MLC	144577	78348	147764	75221	***94%***
01/01, 02/05, 04/16 SVM Polynomial	144577	78348	147764	125904	***157%***
01/01, 02/05, 04/16 SVM Radial	144577	78348	147764	122284	***153%***
Nueva Ecija					
01/01, 02/05, 04/16 MLC	172042	33652	172043	79343	***236%***
01/01, 02/05, 04/16 SVM Polynomial	172042	33652	172043	150791	***448%***
01/01, 02/05, 04/16 SVM Radial	172042	33652	172043	147116	***437%***
WET SEASON					
ENHANCED LEE FILTER					
05/23, 06/11, 06/27 MLC	262397	146648	261850	163508	***112%***
05/23, 06/11, 06/27 SVM Polynomial	262397	146648	261850	167933	***115%***
05/23, 06/11, 06/27 SVM Radial	262397	146648	261850	170916	***117%***
06/11, 06/27, 08/01 MLC	262397	146648	261850	150632	***103%***
06/11, 06/27, 08/01 SVM Polynomial	262397	146648	261850	175929	***120%***
06/11, 06/27, 08/01 SVM Radial	262397	146648	261850	172212	***118%***
06/27, 08/01, 08/20 MLC	262397	146648	261850	151020	***103%***
06/27, 08/01, 08/20 SVM Polynomial	262397	146648	261850	189332	***129%***
06/27, 08/01, 08/20 SVM Radial	262397	146648	261850	181676	***124%***
08/01, 08/20, 09/05 MLC	262397	146648	261850	174469	***119%***
08/01, 08/20, 09/05 SVM Polynomial	262397	146648	261850	205499	***140%***
08/01, 08/20, 09/05 SVM Radial	262397	146648	261850	205161	***140%***
NO FILTER					
05/23, 06/11, 06/27 MLC	262397	146648	261850	182559	***125%***
05/23, 06/11, 06/27 SVM Polynomial	262397	146648	261850	190378	***130%***
05/23, 06/11, 06/27 SVM Radial	262397	146648	261850	190850	***130%***
06/11, 06/27, 08/01 MLC	262397	146648	261850	154697	***106%***
06/11, 06/27, 08/01 SVM Polynomial	262397	146648	261850	191159	***131%***
06/11, 06/27, 08/01 SVM Radial	262397	146648	261850	186352	***127%***
06/27, 08/01, 08/20 MLC	262397	146648	261850	147731	***101%***
06/27, 08/01, 08/20 SVM Polynomial	262397	146648	261850	196716	***134%***
06/27, 08/01, 08/20 SVM Radial	262397	146648	261850	194279	***133%***
08/01, 08/20, 09/05 MLC	262397	146648	261850	180239	***123%***
08/01, 08/20, 09/05 SVM Polynomial	262397	146648	261850	216987	***148%***
08/01, 08/20, 09/05 SVM Radial	262397	146648	261850	213274	***146%***

The classified image demonstrated high accuracy in each season was selected as input in image differencing to determine the irrigated and rainfed rice areas. The rice areas derived from dry season represent the irrigated rice area while the rice areas derived from wet season represent the irrigated and rainfed rice. The final updated rice area map showing the irrigated and rainfed rice area in selected municipalities in Nueva Ecija and Pangasinan are shown in Figure 5. The total rice area derived from ASAR statistics is approximately 193,871 hectares with 88,805 hectares irrigated rice or 21% of the total acreage and 105, 066 hectare rainfed rice or 24% of total acreage. The total area for non-rice including water, built-up and other vegetation is approximately 239,105 hectares or 55% of the total area mapped. The irrigation map covering the study area was overlain in the rice area map produced. Results of the validation were promising.

The rice acreage of irrigated and rainfed rice for each municipalities in Nueva Ecija and Pangasinan are shown in Figure 6 and Figure 7, respectively. The ASAR-derived rice acreage and harvested area from farmers' survey were analyzed statistically using T-test to determine the correlation of the values (Table 3). The null hypothesis is the mean value of ASAR-derived rice area is equal to the mean value of LGU data. If $p \geq 0.05$ the null hypothesis is true, otherwise if $p \leq 0.05$ the null hypothesis is false. At the local level, the ASAR-derived rice acreage for irrigated and rainfed rice ecosystems were compared separately with the area harvested from farmers' survey for both provinces. At the regional level, the total area derived from ASAR regardless of rice ecosystem was compared with the total area harvested from farmers' survey. Results showed that the acreage derived from remote sensing was comparable to the government reported statistics.

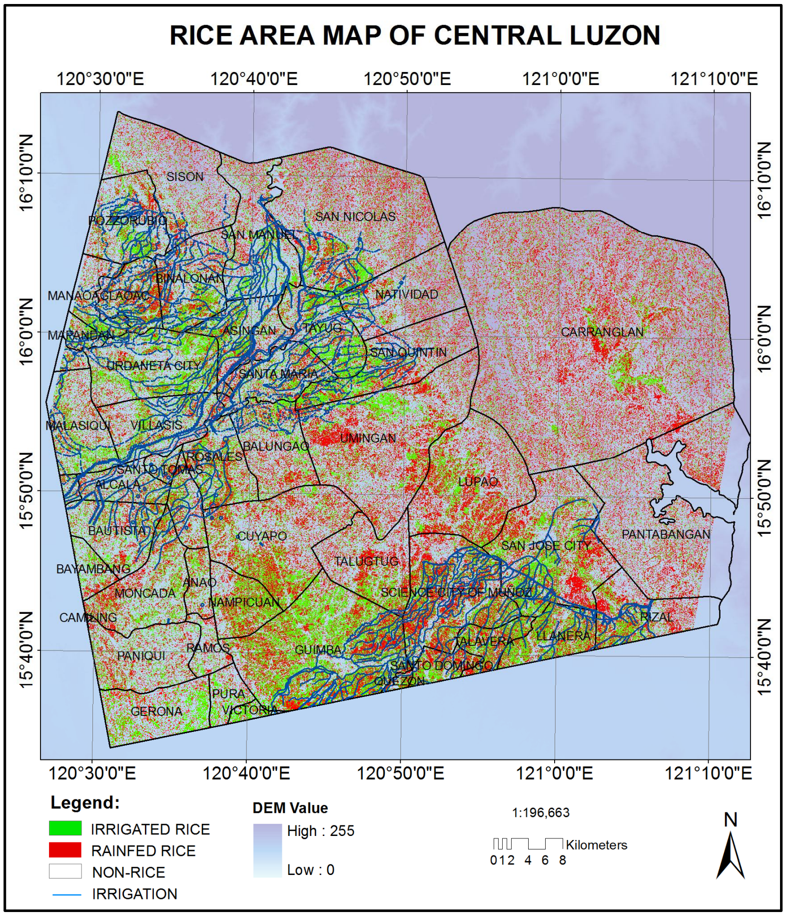

Figure 5. The map of irrigated and rainfed rice areas in some municipalities in Nueva Ecija and Pangasinan.

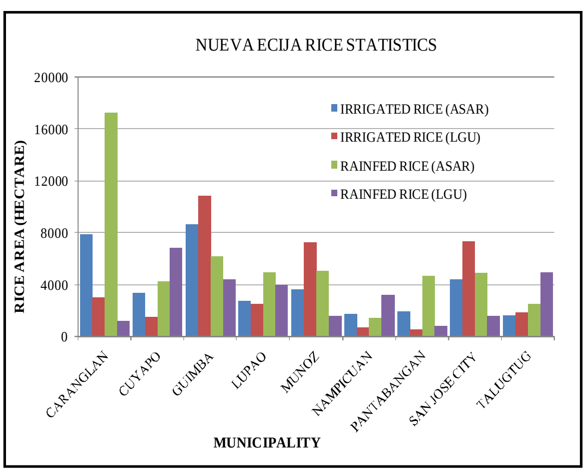

Figure 6.The ASAR-derived rice area and farmer survey statistics for Nueva Ecija.

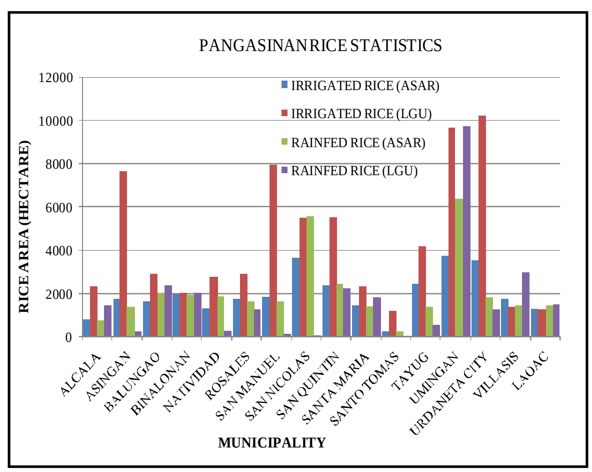

Figure 7.The ASAR-derived rice area and farmer survey statistics for Pangasinan.

Table 3. Statistical result of comparing ASAR-derived rice area with the government reported statistics.

ASAR-DERIVED VS. LGU RICE AREA	df	P-value
NUEVA ECIJA		
IRRIGATED	16	0.984
RAINFED	16	0.148
IRRIGATED & RAINFED	34	0.255
PANGASINAN		
IRRIGATED	30	0.005
RAINFED	28	0.629
IRRIGATED & RAINFED	60	0.073
CENTRAL LUZON		
IRRIGATED	48	0.047
RAINFED	46	0.192
IRRIGATED & RAINFED	96	0.725

5. CONCLUSION

This study demonstrated that multi-temporal ENVISAT ASAR data with 30 meters resolution could be used for mapping planted rice areas and estimating the rice hectarage. Six ENVISAT ASAR images that could generate four multi-temporal color composite images are enough to determine the rice cultivation pattern as a function of different planting dates. Likewise, the application of MLC and SVM methods to the color composite images delineated rice production areas for dry and wet cropping seasons. The use of Enhanced lee filter also improved the classification accuracy. The mapping methodology developed was able to identify not only rice fields but the differences in rice ecosystems, irrigated and rainfed, and also provided an accurate assessment of the rice acreage of these two ecosystems. Thus, the mapping procedure developed demonstrates the potential of remote sensing for objective and accurate method of rice area estimation.

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