APPLICATION OF MULTI-TEMPORAL RADARSAT-2 BACKSCATTERING FOR MONITORING OF PADDY-PLANTING STAGES IN MALAYSIA

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ABSTRACT: *Oryza sativa* **(**paddy) is a global staple food, supply more than 50% of all calories consumed by the entire human population. In Malaysia, food security level ranks second among South-East Asian nations. However, the annual dependency on food imports was still very high. Various efforts have been carried out by the relevant government agencies to increase paddy production. This includes a collaboration project undertaken by Malaysian Remote Sensing Agency and Department of Agriculture Malaysia in monitoring of paddy planting stages. Conventionally, monitoring was done by field survey required a lot of human resources, time consuming and coverage limitation. In this collaboration project, multi-temporal Radarsat-2 images within 11 to 14 days acquisition together with cadaster lot and paddy crop calendar were used to classify four (4) major paddy-planting stages such as ploughing, irrigating, planting and harvesting. Result indicate that Radarsat-2 time-series images were highly beneficial in differentiating paddy planting stages with an accuracy of 94.17%. Four (4) backscatter range (sigma naught) were identified which is between -10 to -7, -11 to -23, -6 to 0 and -10 to -5 for ploughing, irrigating, planting and harvesting, respectively. This is an essential information for machinery, irrigation and logistics planning, faster, efficiently and cost effective. The effectiveness study shown that the monitoring through satellite images saves time by 50% compared to field survey and monitors 100% of the total granary.

1. INTRODUCTION

Food security, water security, climate change and human health are significance in paddy rice agriculture (Dong & Xiao, 2016). Food security is always a big challenge due to the continuously increasing population and limited land. Rice is the most important staple food not only for Malaysians but also for most of the Asian countries, supply more than 50% of all calories consumed by the entire human population (Irri). In Malaysia, food security level ranks second among South-East Asian nations (Star, 2018). However, the annual dependency on food imports was still very high (Lopez, 2019)**.** In order to achieve high level of self-sufficiency in rice production, effective management of paddy cultivation is crucial (He, Li, Wang, Dai, & Lin, 2018). Conventional paddy cultivation management required a lot of human resources, time consuming and coverage limitation, which is not practical at a large spatial extent and for long-term monitoring and analysis (He et al., 2018).

Nowadays, remote sensing images with high temporal resolutions play an important role in crop management and soil conditions for farm management especially at large scale areas. Previous studies have used optical imagery such as Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat to monitor paddy growth phenology; however, they are frequently contaminated by clouds (Tian, Wu, Wang, & Niu, 2018). Therefore, many studies utilize the advancement of SAR satellite images for paddy growth phenology especially in China (He et al., 2018; Li et al., 2016; Shao et al., 2001; Zhang, Liu, Su, & Wang, 2014), Vietnam (Minh, Avtar, Mohan, Misra, & Kurasaki, 2019), Myanmar (Torbick, Chowdhury, Salas, & Qi, 2017), Europe (Nguyen & Wagner, 2017), as well as Malaysia (Rasit et al., 2016). SAR can acquire “cloud-free” images in all weather conditions, capable of night-time operation, sensitive to the dielectric and geometrical characteristics of the plants, can use different imaging parameters, such as the incident angles and the polarization configurations of the sensor, to obtain a wealth of information (Liu et al., 2019). In terms of correlation of different radar observables to rice biophysical parameters, many researchers have obtained successful results in rice planting monitoring using X-band and C-band sensors (He et al., 2018). However, the backscattering at X-band may provide less information on the structure of rice plants than that at C-band. Most studies utilized predominantly single polarization SAR data to retrieval biophysical parameters (Li et al., 2016) and HH polarization data have been used in many paddy mapping studies (Park et al., 2018).

In Malaysia, there are four major activities during paddy growth period or phenology, namely ploughing, irrigating, planting and harvesting. Location and phenological stages of paddy crops are useful for policymakers to protect crops and minimize productivity loss (Minh et al., 2019). In case of any irregularity like late/early irrigation and delayed planting, the effects are visible at the end of production, when the production is lower than expected (DOA, 2014). To face this challenge, Malaysian Remote Sensing Agency (MRSA) in a collaboration with Malaysian Department of Agriculture (DOA) utilize the multi-temporal of Radarsat-2 C-band with HH polarization for monitoring of paddy planting stages. The specific objectives identified were:

1. To analyze the paddy temporal backscatter behavior during ploughing, irrigating, planting and harvesting activities;
2. To develop a methodology for monitoring paddy-planting stages using multi-temporal Radarsat-2 satellite images towards an effective management in paddy cultivation; and
3. To apply the develop methodology into WebGIS application system for operational.

2. METHODOLOGY

2.1 Study area

This study was conducted at Integrated Agriculture Development Area (IADA) Barat Laut Selangor, which located at Selangor State cover an area of approximately 20,030 hectare of rice fields area (Figure 1). The site is characterized by its flat topography and wide variety of agricultural crops and plants including rice, oil palm, vegetables, and fruits. The fields are generally small and are clearly delineated by the ditches, rice field boundary and roadways, which separate them. There are two planting season which are Main-Season (July until December) and Off-Season (March until June) and the weather is cloudy and rainy most of the year, making the soil moisture content quite high. This site also among the highest paddy yield production in Malaysia which produce around 10tonne/ha per season.

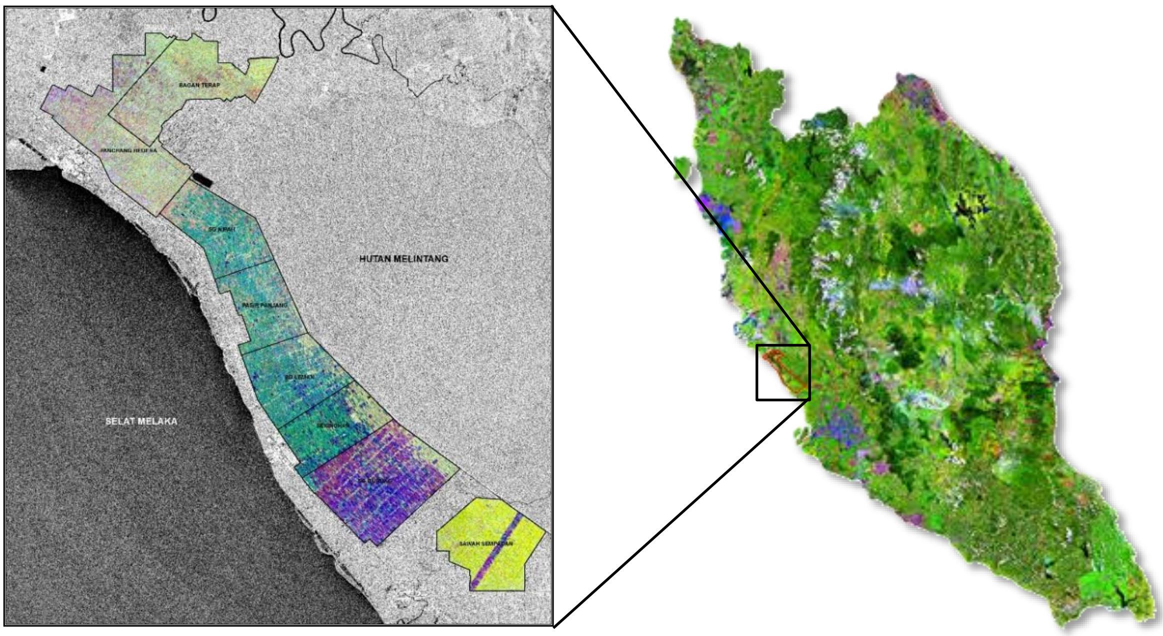


Figure 1: IADA Barat Laut Selangor Granary Area

2.2 Data collection

Paddy's cultivation practices in Malaysia is twice a year based on double cropping. It is important to identify the target dates for image acquisition according yearly paddy crop calendar. The growth calendar stipulates the classification of major activities during paddy growth period month which are timing of ploughing, irrigating, planting and harvesting. There are four stages of planting schedule for IADA Barat Laut Selangor for both off-season and main-season as shown in Table 1. The multi-temporal Radarsat-2, C-band, HH polarization image used as shown in Table 2. According to Zhang, Yang, Liu, & Wang, (2017) et al. and Phan et al (2018)., among the SAR signals at different polarizations, horizontal (HH) and vertical (VV) polarizations, the HH backscatter signals are higher and more dominated by specular reflection for the rice canopy and water surfaces rather than the VV backscatter. The National Digital Cadastral Database (NDCDB) lot was acquired from Department of Survey and Mapping Malaysia (JUPEM) as an authority department in land surveys.

Table 1: Paddy crop calendar IADA Barat Laut Selangor

Stage	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
1	2	3	3	3	4	1	2	3	3	3	4	1
2	1	2	3	3	3	4	1	2	3	3	3	4
3	4	1	2	3	3	3	4	1	2	3	3	3
4	3	4	1	2	3	3	3	4	1	2	3	3

Off-season Main-season 1: Ploughing 2: Irrigating 3: Planting 4: Harvesting

Table 2: Multi-temporal RADARSAT-2, C-Band, HH Polarization Acquisition Date

Date Imagery	
Off Season	*Main Season*
6 April 2018	15 October 2018
16 April 2018	25 October 2018
10 May 2018	8 November 2018
24 May 2019	18 November 2018

2.3 Pre-processing

Radarsat-2 pre-processing including re-project, terrain correction and image calibration was done automatically using EASI Modelling PCI Geomatics script which is develop together with MacDonald, Dettwiler and Associates (MDA). The overall methodology flowchart as shown in Figure 2.

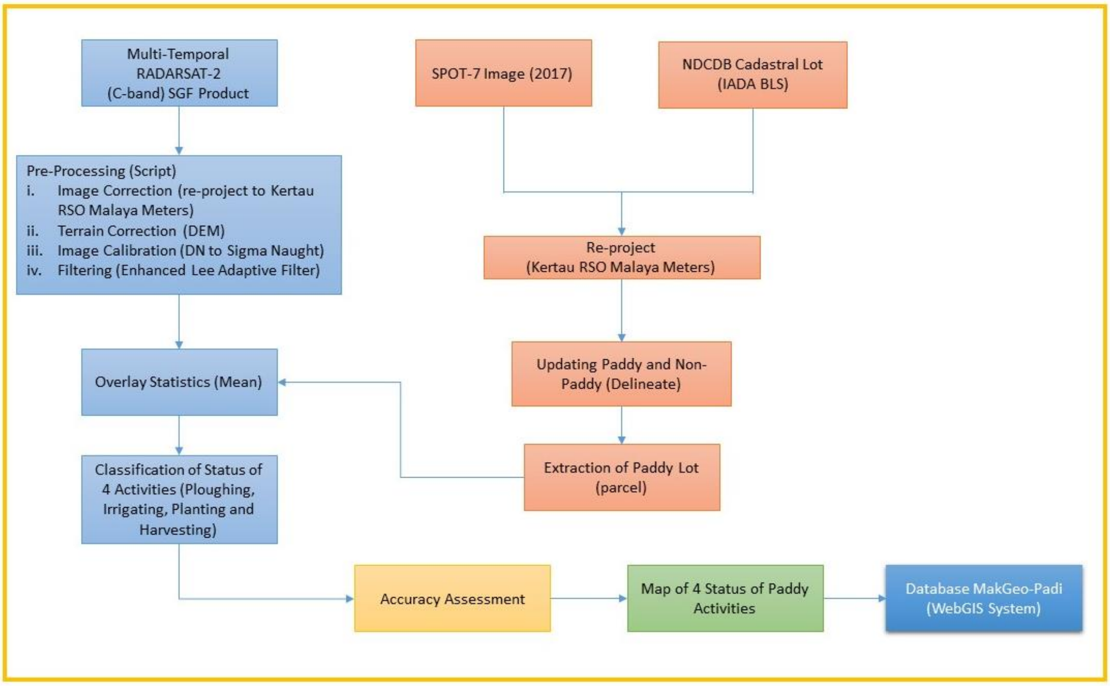


Figure 2: Methodology flowchart to extract paddy status activities

2.3.1 Image Geometric Correction

The multi-temporal SAR Georeference Fine (SGF) RADARSAT-2 (ascending) images was used and geocoded into Rectified Skew Orthomorphic (RSO) Malaya Meter to match with the cadastral lot for overlay processing.

2.3.2 Terrain Correction

Digital Elevation Model (DEM) at 30 m resolution was used as an input variable for paddy classification. According to Park et al. (2018)et al., DEM provides land cover related information and many studies have used elevation data as input variable for land cover classification.

2.3.3 Image Calibration

The image digital numbers were converted to backscatter coefficients (dB) to facilitate making absolute comparison behavior of rice as a function of time (Shao et al., 2001). We run the conversion using Equation (1):

$$\sigma^{\circ}=10*\log_{10}DN^{2} \quad (1)$$

where DN is the digital number of the Radarsat-2 image.

2.3.4 Filtering

Speckle SAR images have high speckle noise; hence, many filters, including Lee, Kuan, Frost, and Gamma MAP have been used to despeckle SAR images. Enhance Lee Adaptive Filter, one of the well-known despeckling filters, was applied in this study to remove noise with 3 x 3 window size.

2.4 Image Processing

2.4.1 Updating Paddy and Non-paddy

To exclude non-paddy areas including building, oil palm and other permanent crop, we update the cadastral lot using SPOT-7 images. This process was done together with DOA and IADA Barat Laut Selangor as an authority department regarding to the study area.

2.4.2 Extraction of Sigma Naught

In the PCI Geomatics (Overlay Statistics) enviroment, the cadastral lot was overlay with Radarsat-2 images to extract the sigma naught by individual lot. The mean statistical function was used for statistical analysis.

2.4.3 Image Classification

In the ArcGIS Software, the value of sigma naught was classify into four (4) different classes, which are ploughing, irrigating, planting and harvesting for each individual lot for the purpose of monitoring the paddy planting activities reflected to the paddy crop calendar.

2.5 Accuracy Assessment

For the accuracy assessment, all of the ground data points, the Normalize Difference Vegetation Index (NDVI) value from SPOT-7 image images were utilized. A total of 120 sample points were located using stratified random sampling for four classes (ploughing, irrigating, planting and harvesting), where the number of points is stratified to the distribution of the classification classes.

2.6 MakGeo-Padi Database

Map of paddy status activities was then stored in the MakGeo-Padi database together with other ancillary data such as owner's profile, farmer's income and yield information. Using information obtained, an entity relationship diagram is design to describe overall relationship of tables and spatial data. In addition, the logical structure is constructed to ensure data is stored in an organized manner (Siti Masayu Yahaya 2015).

3. RESULT AND DISCUSSION

3.1 Crop Phenology

As seen in Figure 3, the backscattering coefficient (dB) value for paddy and other crops are clearly distinct. For paddy, the dB value was recorded low at 20 day of planting (DoP) and high at 100 DoP. The low dB value could be attributed to the irrigating activities, while the high dB value could indicate the presence of paddy crops such as during the planting phase. The phenology for the other crops such as oil palm, vegetable, silver shine, plant cover and fruit tree were consistently high between -5 to -11 dB. Thus, the unique phenological changes of paddy crops especially during irrigating stages can be utilized for discriminating between paddy crop and other objects.

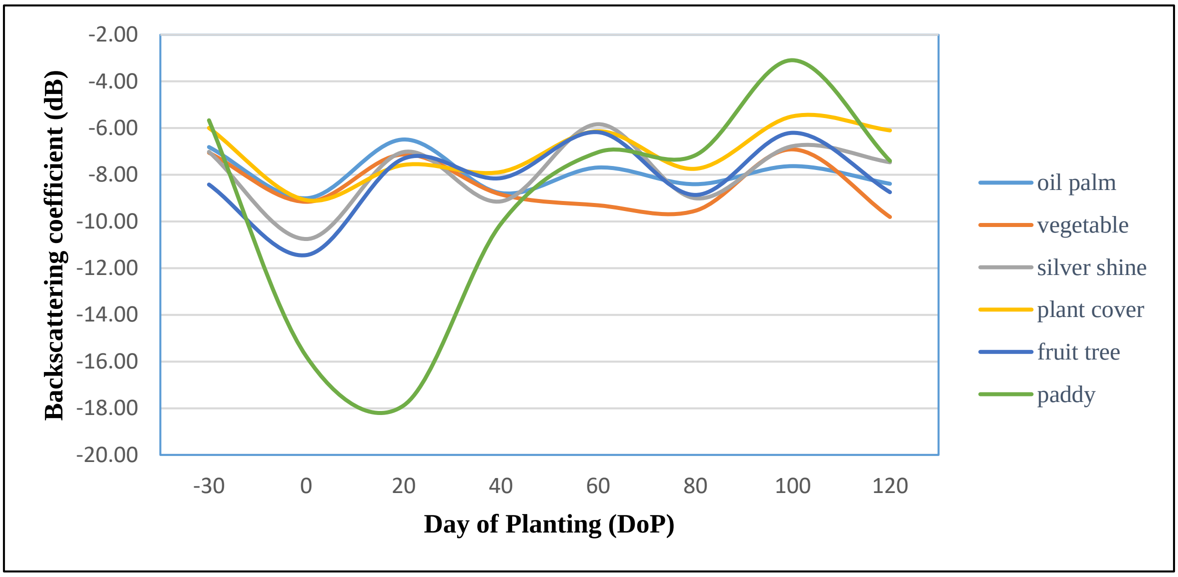
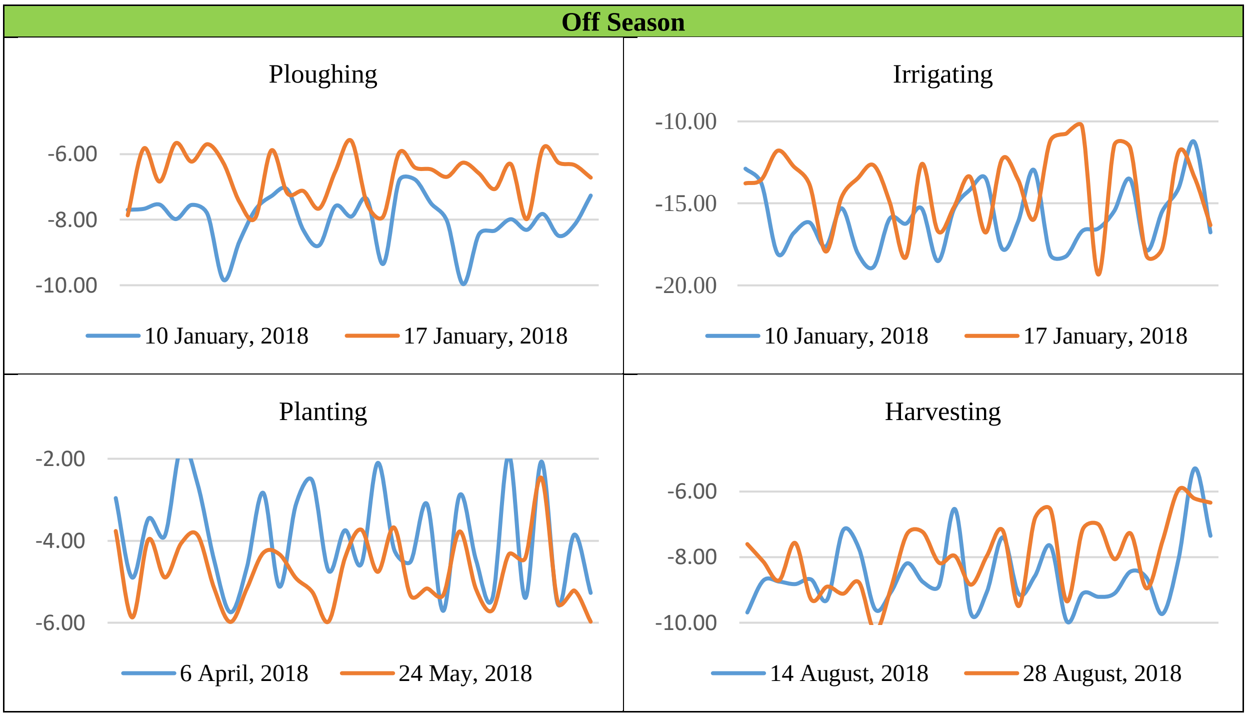


Figure 3: Comparison of Radar Backscattering Value for different Crop Type

3.2 Backscattering Coefficient Range

Figure 4 shows the dB trends for 30 sample collected during ploughing, irrigating, planting and harvesting for both off and main season at two (2) different date. Meanwhile, Table 3 indicate the dB range and ground verification pictures. The results indicate that, the dB value during ploughing was between -10 to -7. The variation depends on the ploughing type either dry or wet ploughing. Ploughing with water indicate low dB compared to dry ploughing. The dB value start drop to during irrigation, which is from -11 to -23, water surfaces are smooth and homogenous, causing reflected radar pulses to be weak (Tian et al., 2018). Until in the early growth stage, the paddy seeding was small, so the contribution of water to backscattering energy was greater than that of paddy rice. Thus, the backscattering coefficient is low in the early stage of paddy rice growth. The dB value becomes high in the middle growth stage after 45 DoP, which is from -6 to 0, the backscattering coefficient of paddy changes distinctly with growth (Tian et al., 2018). However during harvesting period, a decrease in dB was noticed (Minh et al., 2019), which is from -10 to -5, the dB value was quite similar to ploughing activities, since the paddy areas turns into bare and dry field or covered with paddy straw. Therefore, rice crop calendar is crucial to avoid miss classification (Nguyen & Wagner, 2017). The overall results demonstrate that both off and main season bounce the parallel backscattering coefficient range.



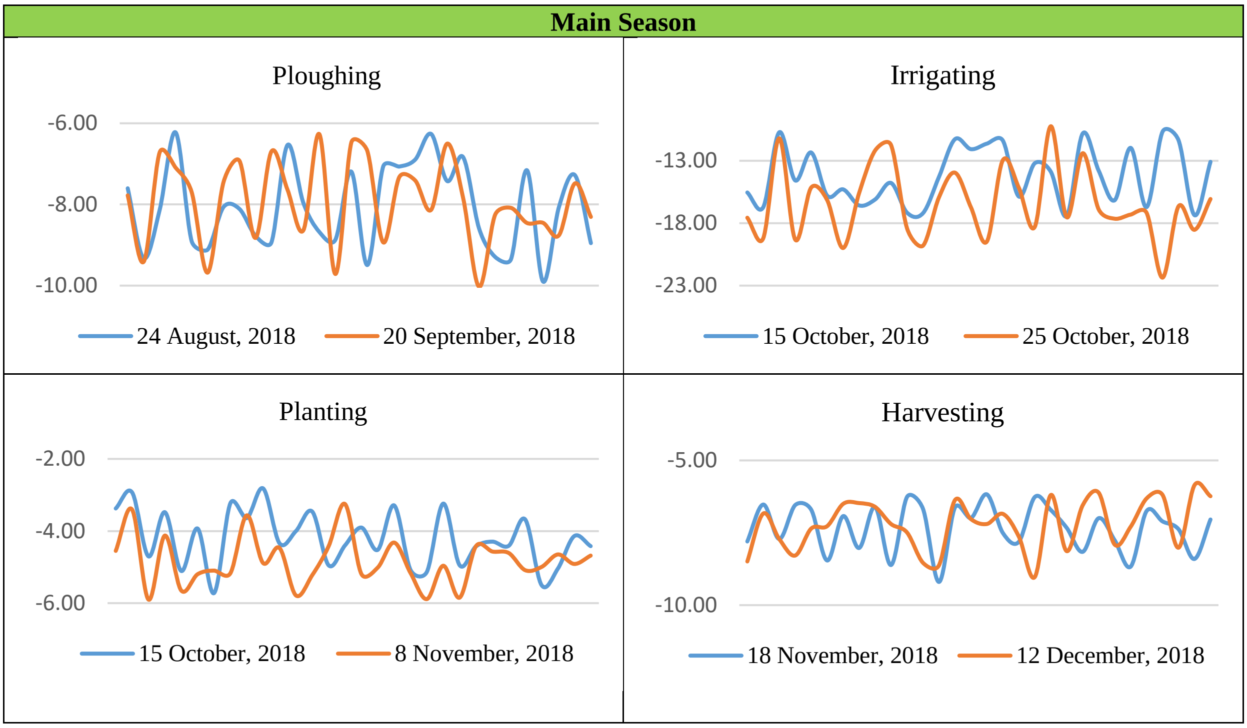
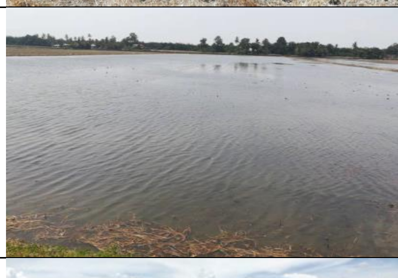


Figure 4: Backscattering coefficient trends of 30 sample areas during ploughing, irrigating, planting and harvesting activities

Table 3: Backscattering coefficient range during ploughing, irrigating, planting and harvesting activities

Planting Activities	**Backscatter Range (dB)**	**Ground Characteristics**	
Ploughing	-10 to -7		
Irrigating	-11 to -23		
Planting (> 45 DoP)	-6 to 0		

Planting Activities	Backscatter Range (dB)	Ground Characteristics	
Harvesting	-10 to -5		

1.1 Paddy Planting Activities Status Map and Accuracy Assessment

Figure 5 shows the capability of multi-temporal Radarsat-2 images in classifying paddy planting status activities including ploughing, irrigating, planting and harvesting using the dB range as identified in table 3. The overall classification accuracy and kappa coefficient reached 94.17% and 0.93, respectively. The map indicate that 19% of the area was done ploughing, followed by 13% irrigating, 40% already planting and 28% harvesting until image dated 8 November 2018. In IADA Barat Laut Selangor or event most of the granary areas, paddy was planted by phase mostly due to technical feasibility and optimal use of the water resource (Monaco et al., 2016).

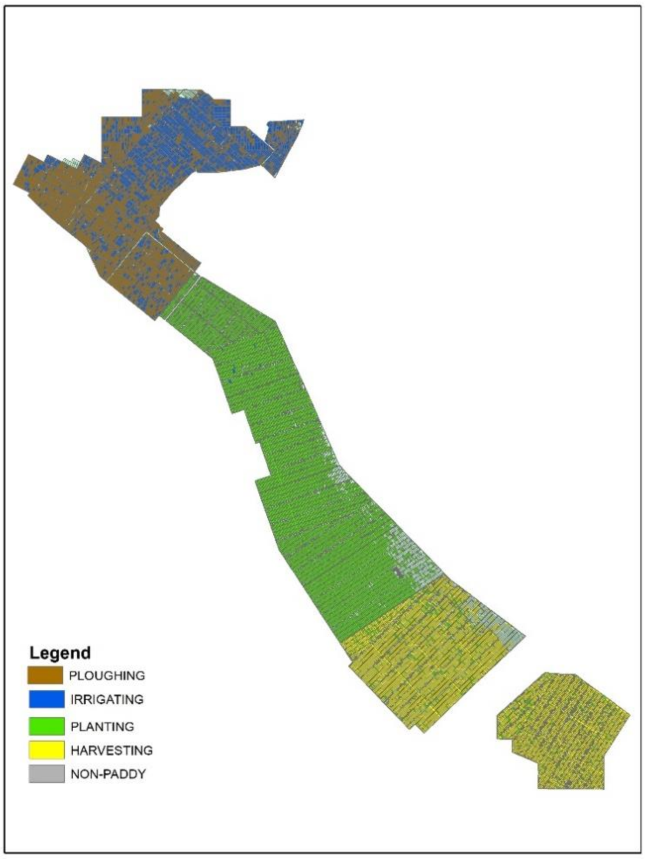


Figure 5: Paddy planting activities status map

Table 4: Accuracy Assessment

Class	*Reference Total*	*Classified Total*	*Number Correct*	*Producers Accuracy*	*User Accuracy*
Ploughing	23	21	20	86.96%	95.24%
Irrigating	41	43	40	95.24%	93.02%
Planting	19	20	18	94.74%	90.00%
Harvesting	37	36	35	94.59%	97.22%
Total	120	120	113		

As shown in table 4, the producer and user accuracy achieved were above 90% for irrigating, planting and harvesting classification. However, the accuracy for ploughing classification was lower compared to other classes, where 86.96% for producer accuracy. The ploughing classification was underestimated since producer accuracy was lower than user accuracy. This might due to the overlapping of dB range especially with harvesting value. The ground characteristics for both activities are quite similar, therefore usage of paddy crop calendar is crucial (Nguyen & Wagner, 2017) and also to ensure the cultivation practices and crop calendar are uniform (Phan et al., 2018).

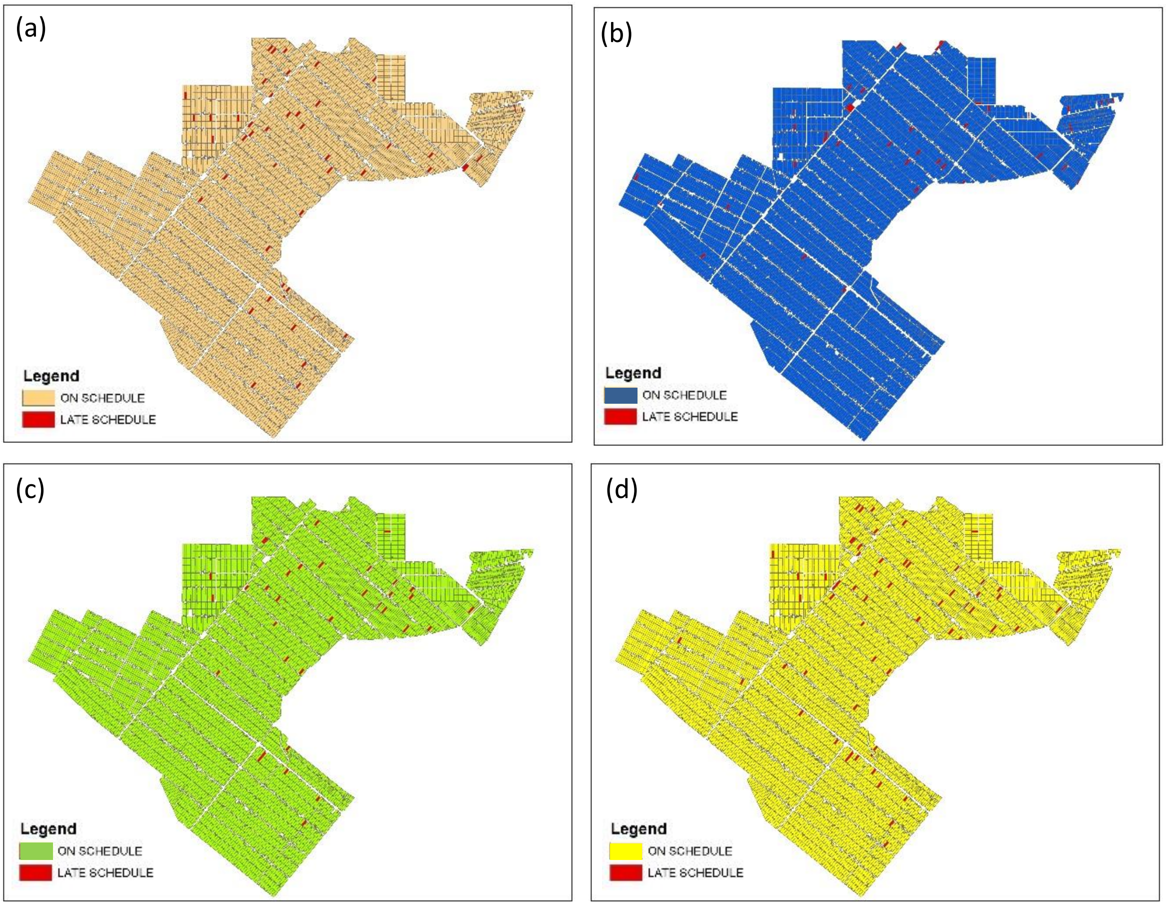


Figure 6: On schedule and late schedule mapping areas of (a) ploughing; (b) irrigating; (c) planting and (d) harvesting activities

Figure 6 demonstrate the advancement of multi-temporal Radarsat-2 images in detecting late schedule paddy planting activities during ploughing, irrigating, planting and harvesting. As shown in figure 6(a), the brown color indicate on schedule ploughing activity, while red color represent late schedule ploughing activity. The lots distribution of late schedule of ploughing activities were scattered with 49 lots indicate 52 hectares. For irrigation activities (figure 6(b)), 44 lots were identified late schedule, indicate 43 hectares. Late irrigation might occur due to water supply problem and this is the crucial phase to ensure paddy-planting presence (Tian et al., 2018). In addition, water stress may lead to lower yields and higher production costs, with consequent repercussions on farm incomes (Monaco et al., 2016). Figure 6(c) shows the on schedule paddy planting by green color and late paddy planting schedule by red color. The results indicate that 34 lots or 37 hectares were late schedule during planting phase. Finally, we identified that 59 lots or 64 hectares of this area were late schedule in harvesting activities. Late harvesting lots distribution were also scattered but not exactly contributed by late schedule during ploughing, irrigating or planting activities.

2. CONCLUSION

This study indicate that Radarsat-2 time-series images were highly beneficial in differentiating paddy planting stages with an accuracy of 94.17%. Four (4) backscattering coefficient range were identified which are between -10 to -7, -11 to -23, -6 to 0 and -10 to -5 for ploughing, irrigating, planting and harvesting, respectively. This accurate and timely paddy planting area statistics and activities status are the requirement of agricultural management and policy-making. This results an essential information for machinery, irrigation and logistics planning, faster, efficiently and cost effective. The effectiveness study by DOA shown that the monitoring through satellite images saves time by 50% compared to field survey and monitors 100% of the total granary.

For operationalization purposes, MRSA disseminate this information via system namely *Maklumat Geospatial Tanaman Padi (MakGeo-Padi*) that can be access by authorized user.

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