Paddy Monitoring in Seberang Perak, Malaysia Using Multi-Temporal Sentinel-1 Data

Azhar Abed Hameed*, Abdul Rashid Bin Mohamed Shariff
Faculty of Engineering, Universiti Putra Malaysia

*Email: Azheraljbory93@gmail.com

Abstract. Rice is considered the main food source for over 40% of the world population and plays a crucial role in countries' food security, food management, and economic aspects. The value of SAR remote sensing in agricultural studies has its source of illumination and not limited to cloud cover. This makes it highly preferable over optical sensors in cloud-shrouded countries. The objective of the study is to assess the capability of Sentinel-1 data for determining paddy planting methods, identifying unhealthy paddy and an attempt made to differentiate rice varieties through correlation of in situ measurements and temporal variation of SAR backscattered signals. Six Sentinel-1 images are stacked to cover the entire paddy lifecycle. The correlated field data and plant backscatter showed that transplanted paddy has backscatter higher than broadcasted paddy. Two drops of paddy backscatter coefficient occurred, the first one, at the reproductive stage when paddy was attacked by bacteria and the second drop was at the ripening stage due to the attack of pests. The five rice varieties planted in Seberang Perak, Malaysia had the backscatter with insignificant differences that cannot confirm the Sentinel-1 capability to differentiate planted rice varieties. According to the obtained results, the time series of Sentinel-1 data has the capability for paddy rice growth monitoring.

Keywords: paddy monitoring, unhealthy paddy, transplanted and broadcasted paddy, rice varieties, multi-temporal backscatter

1. Introduction

With rapid economic growth and an increase in population, food security and management have become an urgent issue due to its importance in fulfilling the people's needs for food around the world. Optical remote sensing has a high capability for crop monitoring, but it is limited by solar illumination and unable to penetrate cloud cover. However, synthetic aperture radar (SAR) has a high capability for paddy monitoring, hence it showed great performance to classify, monitor and estimate yield of paddy especially in the tropical and sub-tropical region due to its own source of illumination and all-weather system [1]. The value of synthetic aperture radar (SAR) in paddy studies lies in its sensitivity to plant moisture content and geometry of canopies which can perfectly be used to discriminate paddy from other land features [2]. Synthetic Aperture Radar (SAR) can be utilized for monitoring rice growth based on its temporal resolution and this works efficiently after field flooding followed by fast biomass raise which supports the backscatter signal.
Another usage for synthetic aperture radar (SAR) in agriculture is yield estimation [3]. C-band of the sensor can be used to overcome the lack of biophysical and growth ground-based data. Therefore, it showed high performance due to its high spatial resolution for paddy monitoring, examines the relationship between backscatter and biophysical changes and yield estimation [4]. C band of Synthetic aperture radar (SAR) of dual-polarization (HV, VV) can be used for detecting the paddy field with acceptable accuracy [5]. VH backscatter can be exploited for paddy monitoring due to its strong correlation with rice physical parameters especially at the reproductive stage when the effect of water and soil moisture decreases and the backscatter is only from the canopy [3]. Synthetic aperture radar (SAR) has a high capability for disease detection and paddy fields attacked by pests through correlation of in situ measurements [6]. Some areas are subjected to many disasters such as floods, drying and intrusion problems which affect farmers and may destroy their crops and fields. Yield productivity can be determined by biomass comparison with records of former years. Many algorithms can be used to classify and predict yield, for example, by use of the forest regression model. Sentinel-1 has shown high appropriateness for this purpose at the regional scale [7].

SAR images with high resolution were utilized to identify rice areas, monitor phonology and assess yield production [8]. Multi-temporal data of Sentinel-1A SAR along with NDVI derived from Landsat data have been utilized to identify the spatial extent of paddy fields [9]. Paddy growth parameters have been examined by utilizing relational models applied on ASAR imagery by exploiting correlation analysis between the backscatter value of remote data and in situ collected data [10]. Time series of TerraSAR and advanced synthetic aperture radar (ASAR) data have been utilized for testing of SAR capability in paddy plants classification. Analysis of SAR images shows that the backscatter coefficient temporally differs through the paddy life span, which increases with the increase of biomass amount from transplanting until the reproductive stage and this backscatter difference is definitely different from other LC features [11]. Correlation between in situ measurements and paddy backscatter, (VV and VH) showed a high correlation, with paddy patterns and water infrastructure while VH is more suitable for paddy in the entire paddy lifecycle [12]. However, the highest correlation for VH backscatter in the reproductive stage due to a decrease of the effect of water and soil moisture and the backscatter will be from canopy only while VV and VH backscatter are highly correlated in the final stage for all different patterns [3].

In this study, multi-temporal Sentinel-1 data have been used for mapping and monitoring a paddy field in Seberang Perak, Malaysia. Although many investigators have been studying paddy backscatter for years, still there are further areas to be explored with respect to the correlation between theories and experimental measurements of rice fields. The goal of this study is to address the following objectives are (i) to investigate the Sentinel-1 potential to identify planting methods (transplanted or open broadcasted), (ii) early detection of different varieties of unhealthy paddy, and (iii) to identify paddy varieties.

2. The Study Area

The study area selected is located within Seberang Perak. The Seberang Perak project covers an area of 80,000 hectares located on the right bank of the Perak River between the Straits of Malacca on the west and Ipoh-Beruas Road on the north (figure1). The study area located at latitude 4.0987° N, and longitude 100.9445° E. The study area of the rice field is 81 hectares and two types of rice are planted in this particular area MR 219 and MR 263. Two planting methods have been used; transplanting and open- broadcasting. This area depends on irrigation rather than rainfall.

2.1. SAR data

The remote sensing data used in this research is from Sentinel-1 which is an Earth observation satellite launched by the European Space Agency. Sentinel-1 works with C-band at central frequency of 5.404 GHz,
with a 12-day repeat cycle and 175 orbits per cycle. Six Sentinel images acquired in ascending mode at different dates (6th March, 18th March, 24th April, 17th May, 10th June and 22nd June) with two polarizations (VV and VH) are used for mapping and monitoring of paddy fields in this research.

2.2 Ground truth and survey data
Samples were collected in Seberang Perak in order to achieve the research goals. Three site visits made coincident with satellite pass to collect the data. The data was collected using Trimble R6 differential GPS. These samples represented the physiographic stratifications, a variety of crop types, and types of planting methods [12]. Different rice parameters such as rice variety, method of the planting (transplanted or broadcasted), paddy phenological stage, height from the ground to the highest /lowest green leaf (cm) were measured for each lot. These parameters were collected for four or five sampling points for each lot and this point collected not within the edge of lots to avoid simple GPS errors such as drifting.

3. Methodology
The methodology used composed of several steps: in the first step SAR data have been acquired (6 Sentinel-1 imagery) to cover the entire paddy lifecycle of Seberang Perak, Malaysia. At the same time or near satellite pass in situ measurements data have been collected for some rice parameters such as age, height and planting methods. The second step was image sub-setting for the 6 images which covers the required area and reduces the data volume as well. Then remote sensing data pre-processing was done, including calibration, speckle filtering, and geometric corrections. Image stacking was created in order to get the temporal backscatter for different land features. Finally image classification to produce rice area maps and analysis of temporal backscatter for paddy by correlating it with in situ measurements for rice parameters was done.

4. Results and Discussion
4.1 Analysis of Sentinel-1 backscatter of land features
The monitoring of rice growth and condition was based on the backscattered signature over more than 100 days. The backscatter of different land features such as water, paddy, oil palm, forest and urban were analyzed as a function of time (Figure 1). The different land feature has different backscatter value. Water has the lowest backscatter because most of the incoming radiation absorbed by water while the urban and forest have the highest backscatter value due to the volume scatter from these two features.

4.2 Analysis of Sentinel-1 temporal backscatter of rice field
Paddy backscatter is in permanent change from planting until harvesting due to the changes in its physical parameters through its short lifecycle on the contrary to other land features where their temporal backscatter almost stable. The start point of the paddy profile (Figure 2) is the backscatter from the soil when the field not flooded yet. After the field is flooded the backscatter decreased dramatically when the incoming radiation is absorbed by water and small amount backscattered toward the antenna. After the first 20 days, the paddy backscatter starts increasing constantly in coincident with the increase of plant age and canopy height.
4.3 Analysis of temporal variation of rice parameters

The investigation of the analysis of temporal variation of the rice parameters and SAR backscatter from Sentinel-1 data at a different stage of paddy growing is the key to grasp the knowledge about the backscattering behavior of the plant. The analysis of the relationship between the backscatter and rice parameters enable us to explore how these parameters affect the paddy backscatter in the different growing stage. The backscatter and plant age are positively correlated, backscatter increases with the increase of plant age (Figure 3). Furthermore, paddy backscatter increases with the increase in height (Figure 4). Both plant age and height are positively correlated with paddy backscatter and correlation coefficient accounts for \( R^2 = 0.8327 \) and \( R^2 = 0.7711 \) respectively.
4.4 Determining planting method of paddy

One of the objectives of this study is to identify the methods used to plant paddy by exploiting SAR sensitivity to crops patterns in the field. Generating temporal variation of backscatter for each mechanism collected points helps us to identify each planting method, through use of the SAR image. Even though both transplanted and open broadcasted rice are planted on slightly different dates, there is the capability to discriminate them from their backscatter. Generally, transplanted paddy has higher backscatter value because the height for the paddy when planted is 15cm on the contrary to the broadcasted seeds. The backscatter for transplanted paddy is higher because its height is higher than broadcasted paddy, and the variation in age affects the backscatter value as well.
Figure 5 shows the temporal variation of backscatter for each planting method which allows us to differentiate between the two methods.

4.5 Identifying rice varieties using multi-temporal backscatter variations

Rice is usually planted with different cropping systems and different agricultural practices which can be observed utilizing different polarization of SAR data. In Seberang Perak, Malaysia, five rice varieties (MS 303, MR 219, MR 297, MR 263 and MR 220 CL 2) were planted with different planting methods and different planting dates during the first season of 2019. MR303 is the first rice variety transplanted on 6th March of 2019 and by correlation in situ measurements with time, we can produce the backscatter profile (figure 6) for this variety. The lesser backscatter occurred in the reproductive stage when the field was flooded. This resulted in the backscatter signals being absorbed at this stage. The backscatter signature starts to increase with the growth of paddy and reached its maximum at the ripening stage due to its height which produces corner reflectance at this stage.

Figure 6. Temporal backscatter variations of paddy.
The mean and standard deviation was calculated for each variety. Table 1 shows the mean and standard deviation for four points for each paddy planted variety planted on different dates and different location in the field. Statistical comparison of the mean values of two varieties shows there is no significant difference between them.

Table 1. Standard deviation and mean for all planted rice varieties.

| days after planting | MS 303 (transplanted) | MR 219 (broadcasted) | MR 297 (broadcasted) | MR 263 (broadcasted) | MR 220 CL2 (broadcasted) |
|-------------------|------------------------|----------------------|----------------------|----------------------|--------------------------|
|                   | mean  | SD    | mean  | SD    | mean  | SD    | mean  | SD    | mean  | SD    |
| 1                 | -19.75| 0.5   | -19.5 | 2.38  | -21.75| 1.25  | -21    | 2.44  | -20.5 | 2.64  |
| 13                | -21.25| 1.7   | -20.75| 1.5   | -22.75| 1.25  | -22.25 | 1.5   | -21.75| 1.25  |
| 48                | -17.75| 1.7   | -18   | 0.81  | -18.25| 0.5   | -18    | 0.81  | -18.25| 0.5   |
| 72                | -15.75| 0.5   | -16   | 0     | -16.75| 0.5   | -16.75 | 0.5   | -15.75| 0.5   |
| 94                | -15   | 0.8   | -15   | 0     | -16.25| 0.43  | -15.75 | 0.5   | -14.5 | 0.57  |
| 106               | -14.75| 0.9   | -15.5 | 0.57  | -16   | 0.81  | -15.25 | 0.95  | -15.25| 0.95  |

4.6 Identifying unhealthy paddy using multi-temporal backscatter of Sentinel-1 data

The analysis of multi-temporal paddy backscatter from Sentinel data is based on the interaction between incoming radar energy with paddy plant and water. This interaction is different from one lot to another based on biomass, stress and plant growth and this can be exploited to identify unhealthy from healthy paddy. Generally, the plant biomass increases with the increase of the paddy age and this causes an increase in plant backscatter. When the paddy is unhealthy, there will be a decrease in the amount of plant biomass, hence, the backscatter will be reduced. Similarly backscatter is increased with the increase of biomass. Different training samples were collected for healthy and unhealthy paddy to examine the signature behaviors of these samples. In the reproductive stage some paddy lots were attacked by bacteria (figure 7). The lots that were attacked by bacteria showed that the backscatter started decreasing. The remarkable difference of backscatter in the reproductive stage helps us to identify between unhealthy and healthy paddy.

Figure 7. Backscatter of health and unhealthy paddy (attacked by bacteria).
By matching unhealthy backscatter with different points of the field in the Sentinel-1 image we obtained some unhealthy points as shown in the Figure 7.

5. Conclusion

The value of RADAR remote sensing in agricultural studies has its source of illumination and not limited to cloudy cover which is highly preferred over optical sensors in cloud-shrouded countries. The extraction of crop information was the main goal for this study due to its important role in decision making, food securing and management. SAR technique is highly sensitivity for crop patterns. Paddy planted by different methods can clearly be identified by comparing the multi-temporal backscatter variation between the two paddy planting techniques. Transplanted paddy has higher backscatter than broadcasted paddy because when it is transplanted, the height of canopy is already 15 cm while the broadcasted paddy is planted as seeds. On the other hand, multi-temporal data of Sentinel-1 SAR along with some training samples from the field have been used to determine unhealthy vegetation. The training samples represent two types of unhealthy paddy, the first one attacked by bacteria and the second is healthy paddy. The bacteria attacked paddy in the reproductive stage which caused a high decrease for multi-temporal backscatter in this period. Comparison between multi-temporal backscatter of healthy and unhealthy paddy is used to identify unhealthy paddy. Determining unhealthy lots in early stages helps to treat the unhealthy paddy area before the source of unhealthiness spreads further. Determining the precise location for unhealthy paddy can be used to spray pesticide on the affected lots individually rather than spraying the whole field which costs a lot more and may negatively affect the healthy lots. In addition, Sentinel-1 capability for identifying rice varieties have been examined and the difference between the multi temporal backscatter was not significant enough to differentiate between them. The limitation of this study was the complexity of data collection from the field in synchronization with the satellite pass. However, SAR remote sensing showed high performance for paddy mapping and monitoring.

Acknowledgements

Authors would like to express my appreciation to everyone who supported and advised me on this task of Project until the end. Thanks to Felcra Seberang Perak manager and staff for the knowledge and assistance delivered throughout the data collection.

References

[1] Jensen, John R. Remote sensing of the environment: An earth resource perspective 2nd Ed. Pearson Education India, 2009.
[2] Foody, G.M., Curran, P.J., Groom, G.B., Munro, D.C., 1989. Multi-temporal airborne synthetic aperture radar data for crop classification. Geocarto International 4, 19–29.
[3] Minh, H. V. T., Avtar, R., Mohan, G., Misra, P., & Kurasaki, M. (2019). Monitoring and Mapping of Rice Cropping Pattern in Flooding Area in the Vietnamese Mekong Delta Using Sentinel-1A Data: A Case of An Giang Province. ISPRS International Journal of Geo-Information, 8(5), 211.
[4] Inoue, Y., Sakaiya, E., & Wang, C. (2014). The capability of C-band backscattering coefficients from high-resolution satellite SAR sensors to assess biophysical variables in paddy rice. Remote Sensing of Environment, 140, 257-266.
[5] Dirgahayu, D., & Parsa, I. M. (2019, June). Detection Phase Growth of Paddy Crop Using SAR Sentinel-1 Data. In IOP Conference Series: Earth and Environmental Science, 280, 1. 012020.
[6] Wu, F., Wang, C., Zhang, H., Zhang, B., & Tang, Y. (2010). Rice crop monitoring in South China with RADARSAT-2 quad-polarization SAR data. IEEE Geoscience and Remote Sensing Letters, 8(2), 196-200.
[7] Clauss, K., Ottinger, M., Leinenkugel, P., & Kuenzer, C. (2018). Estimating rice production in the Mekong Delta, Vietnam, utilizing time series of Sentinel-1 SAR data. *International Journal of Applied Earth Observation and Geoinformation, 73*, 574-585.

[8] Pazhanivelan, S., Kannan, P., Mary, N., Christy, P., Subramanian, E., Jeyaraman, S., ... & Yadav, M. (2015). Rice Crop Monitoring and Yield Estimation through Cosmo Skymed and Terrasar-X: A SAR-Based Experience in India. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 36*, 711-1.

[9] Onojeghuo, A. O., Blackburn, G. A., Wang, Q., Atkinson, P. M., Kindred, D., & Miao, Y. (2018). Mapping paddy rice fields by applying machine learning algorithms to multi-temporal Sentinel-1A and Landsat data. *International Journal of Remote Sensing, 39*(4), 1042-1067.

[10] Yang, S., Shen, S., Li, B., Le Toan, T., & He, W. (2008). Rice mapping and monitoring using ENVISAT ASAR data. *IEEE Geoscience and Remote Sensing Letters, 5*(1), 108-112.

[11] Choudhury, I., & Chakraborty, M. (2006). SAR signature investigation of rice crop using RADARSAT data. *International Journal of Remote Sensing, 27*(3), 519-534.

[12] Le Toan, T., Ribbes, F., Wang, L. F., Floury, N., Ding, K. H., Kong, J. A., ... & Kurosu, T. (1997). Rice crop mapping and monitoring using ERS-1 data based on experiment and modeling results. *IEEE Transactions on Geoscience and Remote Sensing, 35*(1), 41-56.

[13] Canisius, F., Shang, J., Liu, J., Huang, X., Ma, B., Jiao, X., ... & Walters, D. (2018). Tracking crop phenological development using multi-temporal polarimetric Radarsat-2 data. *Remote Sensing of Environment, 210*, 508-518.

[14] Pierce, L. E., Bergen, K. M., Dobson, M. C., & Ulaby, F. T. (1998). Multitemporal land-cover classification using SIR-C/X-SAR imagery. *Remote Sensing of Environment, 64*(1), 20-33.