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Backscatter Analysis Using Multi-Temporal Sentinel 1a Data for Monitoring Rainfed and Irrigated Rice Ecosystems

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ABSTRACT

Rice is a significant staple food crop worldwide, with over half of the global population relying on it for sustenance. In 2016, it fed 4 billion people, which is 56% of the world's population. Rice is grown under different planting conditions and methods, leading to its diverse ecosystem. The rice ecosystem can be classified into four major types: irrigated, rainfed, upland, and flood-prone (IRRI, 1993). Accurate and reliable information on these diverse rice productions is crucial for monitoring, research and development support, and policy decision-making. Synthetic Aperture Radar (SAR) data has been used for rice monitoring because it can solve the problem of cloud cover during rainy or wet seasons when more than 70% of rice is produced (Huke and Huke, 1997). This study analyzed the multi-temporal (2015 to 2022) Sentinel 1A data to monitor two major ecosystems, irrigated and rainfed rice. Backscatter values and features were extracted and analyzed to describe the differences between the ecosystems. Based on the results, there are two different rainfed rice, favorable and unfavorable rainfed. The backscatter of irrigated and unfavorable rainfed have different trends in a year. In addition, using the different backscatter features from Sentinel 1A can discriminate three rice classes. It is best to use VV+VH polarization and the combination of all the features in the classification. Using Random Forest can give higher accuracy compared to Partial Least-Squares Discriminant Analysis (PLSDA) and Support Vector Machine (SVM) in discriminating the irrigated, favorable rainfed, and unfavorable rainfed rice. PLSDA gave the lowest accuracy among the techniques. In preparation for developing an appropriate methodology to discriminate the two rice ecosystems, it is needed to understand the difference between a rainfed and irrigated rice ecosystem.

Keywords: multi-temporal Sentinel 1A, backscatter analysis, rainfed and irrigated rice ecosystems

1. INTRODUCTION

Rice is one of the most important food crops in the world. More than half of the world's population considers it their staple food; in 2016, it fed 56 % (4 billion) of the world's population. It is grown on 157 million hectares, and 90% is in South Asia, Southeast Asia, and East Asia (Zeigler and Barclay, 2008). There are 4 rice ecosystems as categorized by the International Rice Research Institute (IRRI): irrigated, rainfed, upland, and flood-prone. These ecosystems are characterized by wet cultivation except for the upland rice ecosystem. The irrigated rice ecosystem is characterized by leveled, bunded fields and irrigation water available in a natural or supplemental way. While the rainfed rice ecosystem is level to slightly sloping, bunded fields mainly rely on rainfall for their water source. Flood-prone rice ecosystems are situated in level to slightly sloping or depressed fields that are medium to very deep flooding for more than 10 consecutive days. In contrast to these 3 ecosystems, upland rice is grown in level to steeply sloping fields that are rarely flooded, aerobic, and un-bunded (IRRI, 1993).

In the Philippines, there are 2 major rice ecosystems, irrigated and rainfed rice. In 2020, the country planted 4.72 million ha with 3.25 M ha irrigated and 1.36 M ha rainfed. The average grain yield for irrigated and rainfed in 2020 was 4.49 t/ha and 3.32 t/ha, respectively (PSA, 2021). The yield in rainfed rice areas is low compared to irrigated rice areas. Low productivity is due to adverse climate, poor soil, and lack of suitable modern technologies. Research on the rainfed rice ecosystem has intensified over the past years. This technological development is necessary to increase the yield and income of rainfed rice farmers. Most of the rainfed rice farmers are small landholders with limited access to inputs, extension services, information, finance, and markets.

Characterization and delineation of the rice area under different ecosystems are essential for research and development. Remote sensing has been a valuable tool for estimating rice areas and yield. Several studies focused on delineating rainfed rice from irrigated rice by using remote sensing and GIS-based methodologies (Singh and Singh, 1996, D. Kamthonkiat et al., 2005, de la Torre et al., 2021). These studies used vegetation indices extracted from optical images and field data to discriminate the two ecosystems. Moreover, a phenology-based delineation of irrigated and rain-fed paddy fields using Sentinel-2 imagery in Google Engine was performed in Iloilo, Philippines (de la Torre et al., 2021). The study used vegetation indices and existing maps such as irrigation canals, elevation, and slope to perform Random Forest classification. The classification accuracy was 68% for the dry season and 75% for the wet season based on ground-acquired points and very high-resolution imagery. The researchers recommended using the fusion of other satellite imagery (i.e., synthetic aperture radar) to further increase accuracy.

In the Philippines, the Philippine Rice Information System (PRiSM), the first rice monitoring system in Southeast Asia that uses satellite imagery (SAR data) and field data became operational last 2018. It supports the Philippine government by providing timely and reliable rice information based on remote sensing, crop modeling, and information and communication technology. It provides information on planted rice areas, yield, and rice areas at risk and affected by flood and drought (Mabalay, et al., 2022). However, it can't provide data for the delineation of irrigated and rainfed rice since there is no available method to use. The development of the methodology to separate these two rice ecosystems will improve the availability of data for use by the government and non-government organizations. This can ensure the proper distribution of government support and dissemination of appropriate technologies for each ecosystem. Since, each ecosystem requires different resources and technology to increase yield. Yield is affected by cultivation practices and biotic and abiotic stresses.

The SAR can acquire data under any weather conditions such as cloud cover, rain, and snow. Using SAR data can solve the problem of cloud cover during rainy or wet seasons when more than 70% of rice is produced (Nelson et al., 2014). The interaction between waves, rice plants, and water causes variations in backscatter (σ^0) in rice fields. Polarization (i.e., VV, VH) and frequencies (i.e., X-, C-, and L-band) have different relationships with rice plants. For instance, lower frequencies SAR (e.g. C- and L-band) can penetrate better into the rice plant and have the potential to detect soil moisture under the canopy. Meanwhile, the higher frequencies are more sensitive in detecting newly transplanted rice seedlings. Polarizations have different sensitivity in rice (Inuoe et al., 2013, Nelson et al., 2014, Nguyun et al., 2016, Phan et al., 2021). Most rice detection algorithms and methods emphasize agronomic flooding as a critical component. Rice areas are flooded at the start of season (SoS) for land preparation and establishment. In this stage, σ^0 is at its lowest due to specular reflection and low vegetation attenuation. Then, the σ^0 will increase as the biomass increases till the peak of season (PoS), the rice reproductive phase. The backscatter will decrease again towards the harvesting period (Nelson et al., 2014, Pazhanivelan et al., 2015). Rice detection using SAR data relies on the crop's unique temporal signature of backscatter.

The purpose of this study was to analyze the multi-temporal Sentinel 1A data to monitor two major ecosystems, irrigated and rainfed rice. To develop an appropriate methodology, it is needed to understand the difference between a rainfed and irrigated rice ecosystem. The availability of Sentinel-1 developed by the European Space Agency gave an opportunity to monitor rice areas and production for free. Sentinel-1 has provided multi-temporal C-band SAR imagery with 12-day intervals since its launch last 2014 (Aschbacher & Milagro-Pérez, 2012). The study used Sentinel 1A data to analyze the time series backscatter of each ecosystem as the images in the study sites were available from March 2015 to September 2022. The characteristics of backscatter during the planting season in each ecosystem may be the key consideration for discriminating them. The multitemporal data can show the changes in the two rice ecosystems through time, which may allow the opportunity to differentiate and monitor the two rice ecosystems.

2. METHOLDOLOGY

2.1 Location Site and Ground Truth Data

The study focused on the two provinces participating in the PRiSM project, Ilocos Norte and Camarines Sur (Figure 1). The two provinces have different climate types and rice farming practices. Ilocos Norte has Modified Corona's Classification of Climate Type I with two pronounced seasons, wet and dry. According to 45 years of data (1976 – 2020), the annual rainfall is 2082.9 mm which occurs from June to September. Rainfall is primarily brought by Southwest Monsoon and tropical cyclones with the highest rainfall occurring usually in August and low rainfall in January, February, March, April, November, and December (Research Directorate n.d.). The rainfed rice ecosystem in Ilocos Norte is only established during the rainy or monsoon season. In comparison, Camarines Sur is climate Type II, characterized by a very pronounced maximum rain period from July to December and no dry season throughout the year. Then, the months of February to May have the lowest monthly rainfall (BSWM, 2017). In comparison to the situation in Ilocos Norte, this sort of environment is favorable to the rainfed rice growing environment, allowing for establishment all year round. All the irrigated rice fields in both provinces are planted all year round since there are available irrigation canals or supplementary irrigation such as water pumps and wells.

The provinces have municipalities with monitoring fields in rainfed and irrigated rice ecosystems. These monitoring fields acted as the observation fields. A total of 131 rice fields were used for extracting the Sentinel 1A backscatter from irrigated and rainfed rice areas, 74 and 59, respectively (Table 1). These rice fields were at least 500m away from each other with a minimum of 400 m^2 area for monitoring.

The field data were collected in the selected PRiSM monitoring fields in the two provinces. These fields were visited from pre-planting and establishment up to harvest to collect field status (i.e., water and weather conditions), crop management practices, rice stages, and agronomic parameters (i.e., plant height, and plant density). The monitoring visits coincided with Sentinel 1A satellite passes (Mabalay et al., 2022).

Table 1. Number of monitoring fields and images used from 2015 Semester 2 to 2022 Semester 2

Provinces	Monitoring Field (MF)		Sentinel 1A
	Rainfed	Irrigated	
Ilocos Norte	31	39	216
Camarines Sur	28	33	209
Total	59	72	425

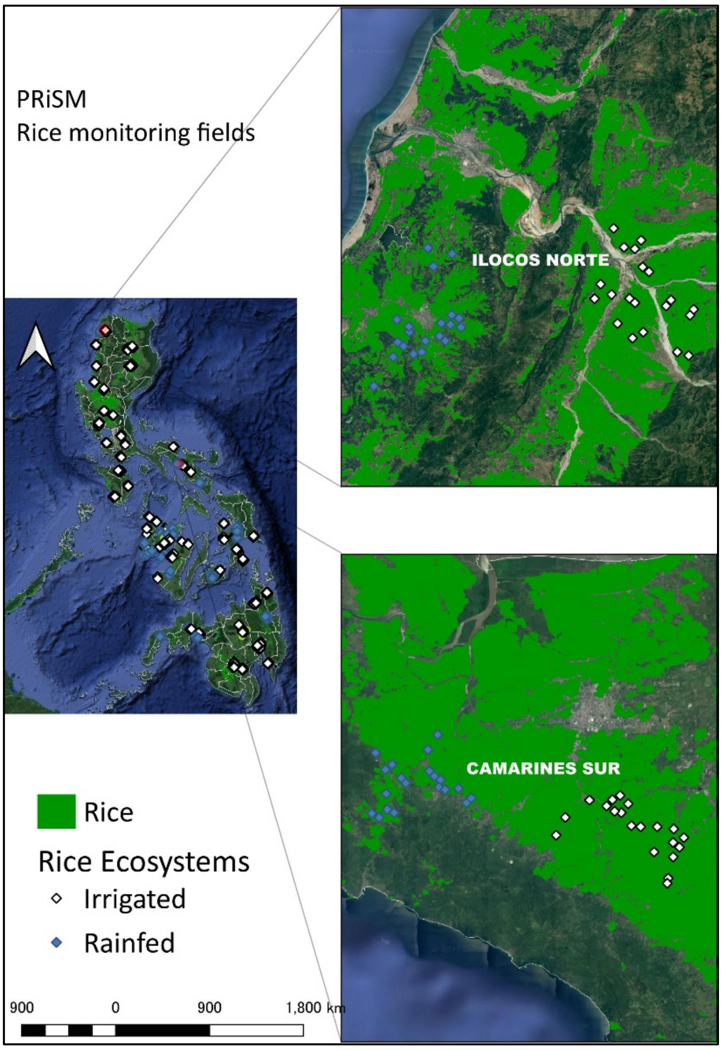


Figure 1. PRiSM monitoring fields are used for field validation data.

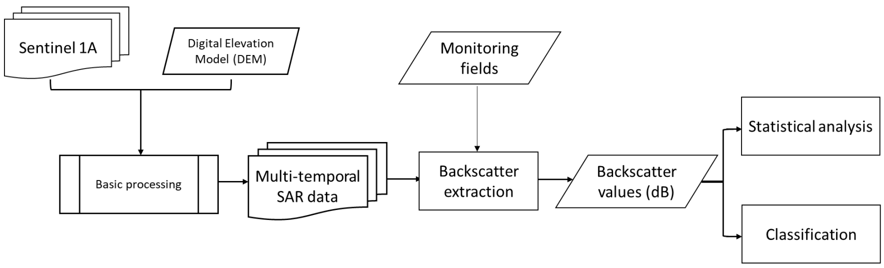


Figure 2. Workplan of the study

2.2 Data Selection, and Processing

The study work plan is shown in Figure 2. The study used SAR data from Sentinel 1A images from March 2015 to September 2022. The images correspond to the planting season of 2015 Semester 2 up to 2022 Semester 1. There are two rice planting semesters in the Philippines based on when the area is established; (1) Semester 1 (dry season) planted from September 16 to March 15, and (2) Semester 2 (wet season) planted from March 16 to September 15 (Mabalay et al., 2022)

The study used Sentinel 1A, the first Copernicus Sentinel series of the European Space Agency (ESA), and a constellation of two polar-orbiting satellites performing C-band synthetic aperture radar imaging (SAR). SAR imagery can be obtained in all weather conditions and can address the issue of cloud cover during the rainy or monsoon season since it can see through clouds (Nelson et al., 2014). It provides dual polarisation capability (VV and VH), with a revisit time of 12 days. In addition, the continuous acquisition of images can cover the whole planting season from establishment to harvesting. Sentinel 1A was selected for SAR image because it was launched in April 2014 and still providing images until now. Moreover, the PRiSM project started monitoring the selected rice areas in the 2015 1st semester.

A total of 425 images in Interferometric Wide Swath Mode (IW) from Tracks 69, 105, and 134 were pre-processed using the processing chain within MAPscape-Rice® software (Nelson et al., 2014). The following steps were done:

a. Strip mosaicking: The Ground Range Detected (GRD) images were mosaicked along their azimuth created long strips in slant range geometry.

b. Co-registration: Images with the same tracks were co-registered in slant range geometry.

c. Time series speckle filtering: This was a filtering for multitemporal images on the basis that reflectivity can change from time to time but should not change because of the position of the resolution element concerning the radar.

d. Terrain geocoding, radiometric calibration, and normalization: Using a digital elevation model (DEM) the images were corrected into slant range image coordinates.

e. Anisotropic non-linear diffusion (ANLD) filtering: This filter smoothens homogenous targets while also enhancing the difference between neighboring areas.

f. Anisotropic non-linear diffusion (ANLD) filtering: This filter smoothens homogenous targets while also enhancing the difference between neighboring areas.

After the basic processing, the final product was a multi-temporal terrain geocoded backscatter (σ^0). Then, these images were stacked for easy extraction of values. Using the QGIS function zonal statistics (mean), the backscatter values (dB) were extracted.

Daily weather data such as precipitation (mm/day), temperature, and soil moisture in the sites were downloaded from the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resource (POWER) Project funded through the NASA Earth Science/Applied Science Program. The weather data especially the precipitation was used in monitoring the rice ecosystem. Rainfed rice ecosystems rely on precipitation for their irrigation water.

2.3 Backscatter Analysis

In preparation for analysis, both VH and VV backscatter values were smoothened using the Savitzky–Golay smoothing method with five weighting coefficient parameters. It is a filter used for a set of digital data points to increase the signal-to-noise ratio without appreciably distorting the signal. The images dates of start-of-season (SoS), peak-of-season (PoS), and end-of-season (EoS) of each semester per year were determined through the generated PRiSM SoS map and field data collected in the monitoring field. The SoS date is the crop establishment or the planting date of the monitoring field (Mabalay et al., 2022). PoS refers to the date when the backscatter attained its peak value, which occurs in rice reproductive phase. While EoS refers in the rice maturity phase to harvesting (Holecz et al., 2013, Nelson et al., 2014, Mabalay et al., 2022). The PoS and EoS dates were computed from the detected SoS dates. Based on the rice growth stages the PoS started from 45 days to 70 days (early to late maturing varieties) while EoS started from 110 to 120 days after SoS. The backscatter values were extracted in these selected images for statistical analysis.

The VH/VV polarization ratio and Radar Vegetation Index (RVI) were computed from the smoothened backscatter values. In rainy and monsoon, vegetation indices (e.g. Normalized Difference Vegetation Index and Leaf Area Index) derived from optical images are difficult to use for vegetation monitoring due to cloud cover. Radar ratios and index can be an alternative for these indices. Kumar et al. (2013) mentioned that RVI can be advantageous for vegetation monitoring because less sensitive to environmental condition changes such as soil moisture than single polarization backscatter. With this, it is more advantageous to use in vegetation monitoring. Equation 1 for RVI computation was modified from the original index with the assumption that the HH backscatter is approximately equal to the VV backscatter and the HV backscatter is approximately equal to the HH backscatter. The equations are as follows:

$$VH/VV\ Polarization\ Ratio = \frac{\sigma^0{}_{(VH)}}{\sigma^0{}_{(VV)}} \quad \ldots(1)$$

$$Radar\ Vegetation\ Index = \frac{4\sigma^0{}_{(VH)}}{\sigma^0{}_{(VV)} + \sigma^0{}_{(VH)}} \quad \ldots(2)$$

Whereas, $\sigma^0{}_{(VH)}$ is the backsctter value (dB) f Sentinel 1A VH polarization while $\sigma^0{}_{(VV)}$ is the backscatter value (dB) of Sentinel 1A VV polarization in each acquisition date.

Different classification analyses were performed to detect the predictability of the two rice ecosystems: Partial Least Square Discriminant Analysis (PLSDA), Random Forest, and Support Vector Machine (SVM). Using R (version 4.2.3), the analyses were done. The packages mixOmics (Rohart, et. al., 2017), randomForest (Liaw & Wiener, 2002), and e1071 (Meyer et. al., 2014) were used for PLSDA, RF, and SVM, respectively. The multitemporal backscatter dataset was divided into 70% training and 30% test datasets to develop the models. The models for delineating the two ecosystems were evaluated using accuracy assessment.

PLSDA is a type of linear classification based on Partial Least Squares Regression (PLSR). It is an alternative analysis to PLSR if the dependent variables are categorical. It is used to build predictive models with multicollinear variables (Rohart, et al., 2017). It also can capture maximum variations associated with the spectra and many descriptor variables with lower correlation. Another classification used in the study was Random Forest (RF). It is a non-linear decision tree classification with a straightforward and highly accurate machine learning algorithm. It handles continuous variables and calculates the average prediction of multiple decision trees (Awad & Khanna, 2015). In this study, RF was tuned using the hyperparameters, ntree and mtry. The ntree is the number of trees while mtry is the number of variables to randomly sample as candidates at each split. The ntree parameter was optimized (from 100 to 1500) based on the root mean square error of the training. Meanwhile, mtry was tuned using the random search in the caret package in R. (Kuhn et. al, 2020).

On the other hand, Support Vector Machine (SVM) is a non-linear classification method that uses points in a transformed problem space that best separates classes into two groups. It works well in high-dimensional datasets such as multi-temporal (Awad & Khanna, 2015). Selection of hyperparameters (i.e., cost and gamma) was performed in the e1071 package framework.

3. RESULTS AND DISCUSSION

3.1 Ground data in monitoring fields

The ground data were collected from the monitoring fields (MF) of the provinces of Ilocos Norte and Camarines Sur in the Philippines (Table 2). Based on the summary of the field monitoring in the two provinces, there are two cropping semesters in Camarines Sur (irrigated and rainfed) and the irrigated rice ecosystem in Ilocos Norte. The cropping system in Ilocos Norte rainfed rice ecosystem is rice-other annual crops (e.g. corn and vegetables). The MFs planted both inbred and hybrid varieties. The irrigated rice ecosystem in Camarines Sur planted earlier rice varieties than the three other sites (90 days maturity). The farmers tend to plant early varieties during the monsoon season to prevent damage due to typhoons and heavy rains. They practice transplanted and direct-seeded establishments in both provinces. The transplanting method is where the seeds are first raised in seedbeds before being planted in the rice field while in the direct seeding method, seeds are directly sown in the rice field (Rice Knowledge Bank, n.d.). Based on the establishment dates in Ilocos Norte MF, the peak of SoS is June to December, and August in irrigated and rainfed, respectively.

Table 2. Summary of monitoring ground data from 2015 Semester 2 (S2) to 2022 Semester 1 (S1)

Details	Ilocos Norte		Camarines Sur	
	Irrigated	Rainfed	Irrigated	Rainfed
Planting semester	2 (S1 and S2)	1 (S2) rice-other crops	2 (S1 and S2)	2 (S1 and S2)
Variety	Inbred/Hybrid		Inbred/Hybrid	
Rice variety maturity	110 - 115	105 - 120	90 - 120	110 -120
Planting method	Transplanted/ Direct seeded		Transplanted/ Direct seeded	
The peak of establishment (SoS month)				
2015S2	June	August	June	
2016S1	January	-	December	January
2016S2	July	August	June	May
2017S1	December	-	December	November
2017S2	June	August	June	August
2018S1	December	-	January	December
2018S2	June	August	August	July
2019S1	October	-	December	December
2019S2	June	August	July	July
2020S1	December	-	December	January
2020S2	No monitoring data due to the pandemic lockdown		June	August
2021S1	January		October	December
2021S2	June	August	July	July
2022S1	December		December	January

3.2 Backscatter of irrigated and rainfed rice

As shown in Figure 3, the multi-temporal backscatter values in VV and VH polarization, VH-VV polarization ratio, and RVI for Camarines Sur and Ilocos Norte irrigated and rainfed rice ecosystems. The black line represents the mean backscatter measurements in each backscatter feature.

In Camarines Sur, it can be shown that irrigated (Figure 3a) and rainfed (Figure 3c) VH polarization backscatter followed the same trend for 15 planting semesters (2015 S2 to 2022 S2). Every semester had a low backscatter value which represents the SoS. This period was the establishment where the rice fields were flooded or soaked with irrigation water. After the SoS, the backscatter increased up to a certain period, this was the PoS. The rice plants were in their maximum vegetative stage to reproductive phase (45 to 70 days after SoS). The backscatter decreased after the PoS indicating that the rice plant was towards the harvesting or EoS.

On the contrary, the irrigated (Figure 3b) and rainfed (Figure 3d) VH polarization backscatter in Ilocos Norte have different trends. The irrigated rice has the same time course as Camarines Sur's irrigated and rainfed rice. The rainfed rice backscatter in both VH (Figure 3.d) and VV (Figure 3.h) polarization still has a low point every semester (SoS). However, the low values in semester 1 were not too low compared to the low values in semester 2. This can be explained that the province has a rice-other crop planting system. The lowest value during semester 2 can be attributed to the establishment of rice or the agronomic flooding in the rice fields while the other low value in semester 1 can be attributed to the land preparation for other crops. Based on the interview, the rainfed rice ecosystem in the province can only be planted once a year during semester 2 (rainy season), and other crops such as corn and vegetables during semester 1 (dry season). Establishments in the area solely rely on rainfall to irrigate their rice fields. This situation can be seen in Figure 3. As the rainy season starts in semester 2 (Figure 3r), the backscatter in both VH (Figure 3d) and VV (Figure 3h) polarization decreased which means the land preparation and establishment started in the sites.

On the other hand, the trend in VV polarization backscatter in both Camarines Sur and Ilocos Norte in irrigated (Figure 3e – 3g) is less sensitive in detecting the SoS within the semester. This is in contrast with the rainfed rice in Ilocos Norte; VV polarization (Figure 3h) follows the same trend as VH polarization backscatter. The SoS in VV backscatter had the lowest value in every semester 2 of each year. Moreover, generally, double peaks can be seen in every semester. These peaks are seen in the growth rice growth stages of maximum vegetative and heading. Furthermore, the backscatter values of VV polarization in both provinces are generally larger than the VH polarization. The same results were shown in the study by Nguyen et. al., (2016).

Moreover, the VH/VV polarization ratio (Figure 3i – 3k) and RVI (Figure 3m – 3p) in both provinces have similar trends. This is due to their almost the same equation using VH and VV polarization (Equations 1 and 2). Generally, the peaks of the ratio and RVI correspond to the PoS in each planting semester while the drop in the values was seen in the establishment and harvesting periods. Either of the two backscatter features can be used in monitoring rice vegetation. They follow the unique backscatter trend of the rice ecosystem.

Figure 4 shows the sample backscatter of Camarines Sur and Ilocos Norte irrigated and rainfed rice ecosystems for 3 cropping semesters (2018 S1 – 2019 S2). The figure shows the corresponding establishment dates in the site per cropping semester. The summary of data collected during the establishment of the sample sites in Camarines Sur and Ilocos Norte is shown in Table 4. All Camarines Sur sample sites used direct seeding for the establishment, meanwhile, Ilocos Norte used transplanting.

Based on the data, the establishments in the sites started when there was rain in the area. The sites (Figure 4a, 4c) with the direct seeded establishment method have the lowest values of backscatter after the establishment in the nearest satellite image acquisition. In contrast, the sites (Figure 4b, 4d) with the transplanted establishment method have their lowest value of backscatter before the establishment date. This can be due to that the fields were soaked or flooded in preparation for the establishment. The land preparation involves soaking the field with water and plowing it 1 - 4 weeks before transplanting. In direct seeding, the rice field is not too flooded until the rice plant emerges to prevent seed damage. SAR backscatter values are at the lowest during this agronomic flooding and land preparation in the rice field. The backscatter values increased as the rice plant until it reached the reproductive stage. Then it started to decrease towards maturity and harvesting.

Table 3. Summary of establishment dates and methods in sample sites in Camarines Sur and Ilocos Norte

Site	2018 S2		2019S1		2019S2	
	Method[1]	SoS date[2]	Method[1]	SoS date[2]	Method[1]	SoS date[2]
Camarines Sur						
Irrigated rice	DS	July 23, 2018	DS	January 15, 2019	DS	May 11, 2019
Rainfed rice	DS	July 11, 2018	DS	January 11, 2019	DS	July 11, 2019
Ilocos Norte						
Irrigated rice	TP	July 8, 2018	TP	October 13, 2018	TP	June 6, 2019
Rainfed rice	TP	July 30, 2018		no establishment	TP	August 8, 2019

[1] Method: DS - Direct-seeded; TP Transplanted
[2] SoS date is the direct-seeded and transplanted days.

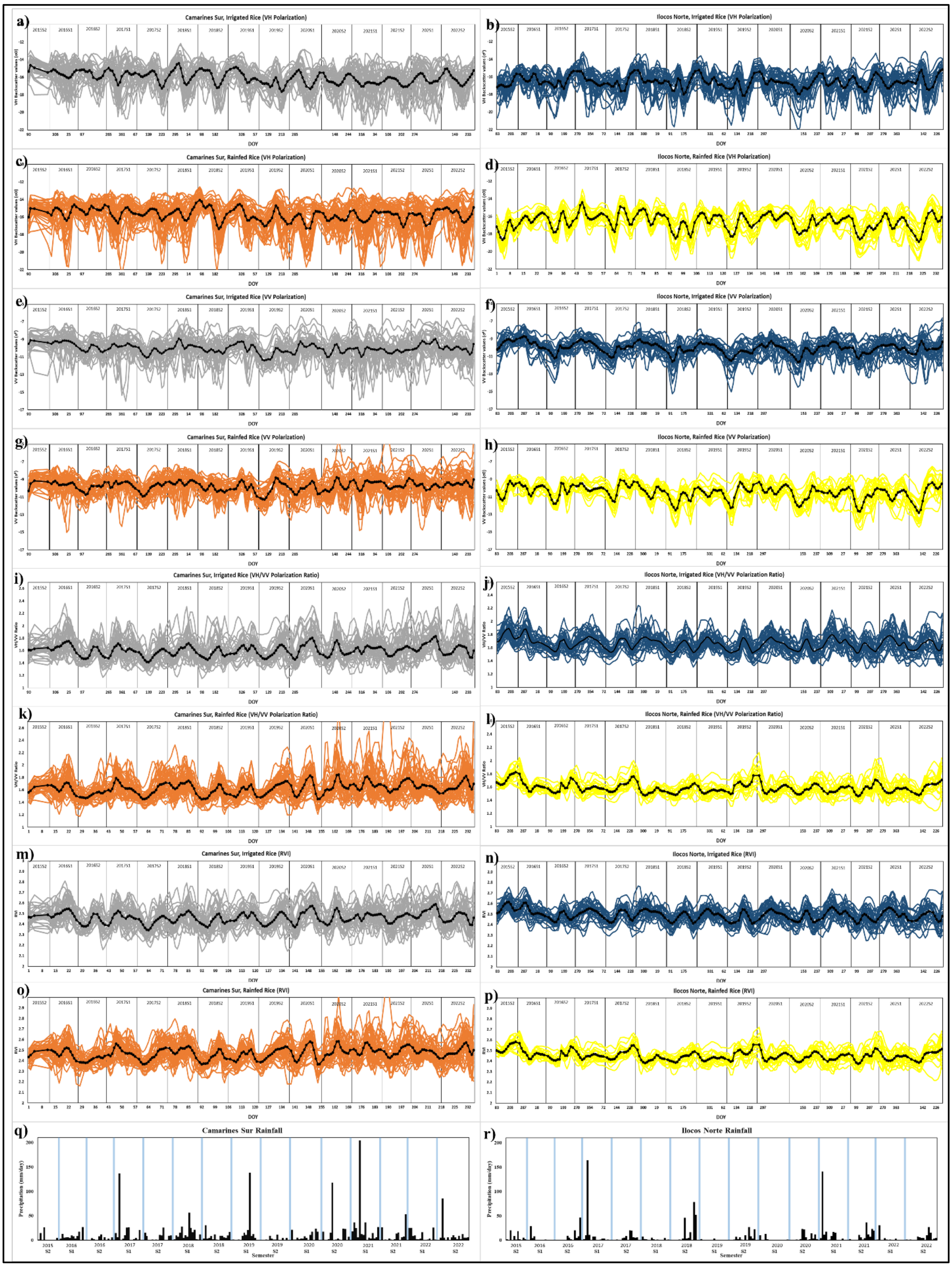
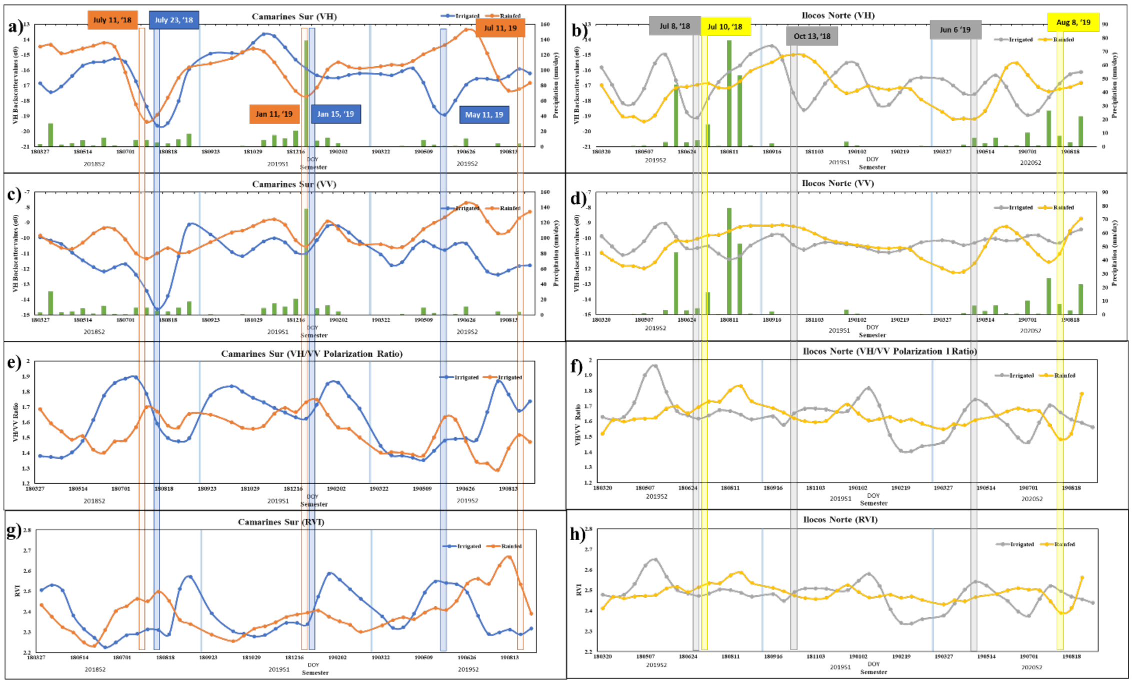


Figure 3. Sample multi-temporal Sentinel 1A VH-VV backscatter values (σ0) from 2015 Semester 2 to 2022 Semester 2; VH polarization in (a) Camarines Sur irrigated rice, (b) Ilocos Norte irrigated rice, (c) Camarines Sur rainfed rice, (d) Ilocos Norte rainfed rice; VV Polarization in (e) Camarines Sur irrigated rice, (f) Ilocos Norte irrigated rice, (g) Camarines Sur rainfed rice, (h) Ilocos Norte rainfed rice; VH/VV Polarization Ratio in: (i) Camarines Sur irrigated rice, (j) Ilocos Norte irrigated rice, (k)

Camarines Sur rainfed rice, (l) Ilocos Norte rainfed rice; Radar Vegetation Index in: (m) Camarines Sur irrigated rice, (n) Ilocos Norte irrigated rice, (o) Camarines Sur rainfed rice, (p) Ilocos Norte rainfed rice; Precipitation data in (q) Camarines Sur, and (r) Ilocos Norte.



Note: The color bars indicate the SoS or the establishment of each monitoring field.

Figure 4. Sample multi-temporal Sentinel 1A VH-VV backscatter values (σ0) from 2018 Semester 2 to 2019 Semester 2: (a) Camarines Sur VH polarization, (b) Ilocos Norte VH polarization, (c) Camarines Sur VV polarization, (d) Ilocos Norte VV polarization, (e) Camarines Sur VH/VV Polarization Ratio, (f) Ilocos Norte VH/VV Polarization Ratio, (g) Camarines Sur RVI, (h) Ilocos Norte RVI

3.3 Statistical Analysis of backscatter values

Different classification techniques were performed to discriminate the two rice ecosystems (Table 4). The extracted backscatter values in SoS, PoS, and EoS were used in the classification since the number of satellite images was not equal in each province. A combination of different backscatter features was used in the analyses; (1) VV polarization backscatter values only (2) VH polarization backscatter values only, (3) VV polarization backscatter values, and VH polarization backscatter values, (4) VH/VV polarization ratio, (5) RVI, (6) VH/VV polarization ratio and RVI, and (7) all the backscatter features. There were three classes used (a) irrigated rice, (b) favorable rainfed rice, and (c) unfavorable rainfed rice. The rainfed rice was classified into two since they have different practices and farming systems. The methods were evaluated using the accuracy assessment.

Based on the tuning in PLSDA, the different backscatter features used the same parameter (ncomp) to perform the classification. According to the accuracy assessment, the highest accuracy in discriminating the three classes was using the VV polarization, and VV + VH polarization, 0.7941 and 0.7941, respectively. However, all the backscatter features have below 0.85 (85%) which is the standard of classification results.

In performing the Random Forest Regression, the ntree parameter was the same with all the analyses while different values of the parameter, mtry. This was optimized based on the lowest calibrated RMSE. Based on the results, the VV+VH polarization and using all the backscatter features gave the highest accuracy, 0.9211 (92.11%) with 0.8696 Kappa.

In SVM classification, the parameters, cost, and gamma were defined using the function tune.svm( ) with 10-fold cross-validation error measurement. For all the backscatter features the best cost and gamma are 100 and 0.001, respectively. The VV+VH polarization performed the best accuracy with 0.8684 (86.84%).

Based on the classification results, it is better to VV+VH polarization and all the features in the classification across the three techniques. Furthermore, using Random Forest can give higher accuracy compared to PLSDA and SVM. PLSDA has the lowest accuracy among the techniques.

Table 4. Overview of different classification model performances using different backscatter features

Backscatter features	PLSDA		Random Forest			SVM		
	ncomp	Accuracy	mtry	Accuracy	Kappa	Gamma	Cost	Accuracy
VV Polarization	2	0.7941	7	0.8684	0.7826	0.001	100	0.8158
VH Polarization	2	0.7353	10	0.8947	0.8282	0.001	100	0.8421
VV+VH Polarization	2	0.7941	7	0.9211	0.8696	0.001	100	0.8684
VH/VV Polarization ratio	2	0.6765	10	0.7632	0.6100	0.001	100	0.7632
RVI	2	0.6471	15	0.7105	0.5234	0.001	100	0.7632
Ratio+RVI	2	0.6471	1	0.7895	0.6502	0.001	100	0.7895
Polarization+Ratio+Index	2	0.7353	85	0.9211	0.8696	0.001	10	0.8158

4. CONCLUSION

The study aimed to analyze the multi-temporal Sentinel 1A data to monitor two major ecosystems, irrigated and rainfed rice. This is to understand the difference between the two rice ecosystems, irrigated and rainfed rice. The study used Sentinel 1A data to analyze the time series. Some backscatter features from the two polarizations were extracted to assess the potential of discriminating between the two rice ecosystems.

In this study, there were two types of rainfed ecosystems in the selected provinces: favorable and unfavorable. The favorable rainfed rice has the same practices and farming system as the irrigated rice. Low points in the trend mark the start of the season (SoS) or the crop establishment. They have 2 lowest values in a year which means they established rice at least 2 semesters in a year. The unfavorable rainfed rice also has 2 low values in the trend for each year however, the low valueduring semester 2 is lower than the semester 1. This is because, in the farming system, farmers only plant rice once a year in the area during the rain is abundant and other annual crops during dry season.

With different establishment methods, direct seeding, and transplanting, the detection of SoS differs. In the direct seeded field, the backscatter's lowest value can be seen after the establishment, meanwhile, in transplanted rice, it can be seen before the establishment. In direct seeding, the rice field is saturated to 1 cm water depth until the rice plant emerges to prevent seed damage. On the other hand, in transplanted rice, the rice fields are usually flooded or soaked in water in preparation for transplanting.

Using the different backscatter features from Sentinel 1A can discriminate three rice classes. It is better to use VV+VH polarization and the combination of all the features in the classification across the three classification techniques, PLSDA, RF, and SVM. Using Random Forest can give higher accuracy compared to PLSDA and SVM in discriminating the irrigated, favorable rainfed, and unfavorable rainfed rice. PLSDA gave the lowest accuracy among the techniques.

The VH-VV polarization ratio and the Radar Vegetation Index have the same trend in response to rice growth. Thus, either of the two can be used in monitoring rice development. Furthermore, in preparation for developing an appropriate methodology to discriminate the two rice ecosystems, it is recommended to analyze other features of different satellite images further. A good opportunity to use different sensors to further describe the difference between these two ecosystems based on the rice phenology. In addition, it is recommended to study water monitoring in both ecosystems since water availability is the main difference between them.

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