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Sentinel-1 Dual-Polarization Data Analysis to Identify Paddy Growth Stages in Indramayu District

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Abstract. Sentinel satellite imagery using radar sensors for one particular area with the same orbit can be compared every 6 days and freely available to be downloaded. This advantage can be exploited to regularly identify land surface changes in a particular region. Paddy is a fast-growing crop with an approximately 120-day life cycle and specific growth stages related to phenological aspect, especially to changes in plant height. Hence, paddy growth stages can be monitored using this radar sentinel satellite with dual polarization data. Radar satellite is also cloud-free and therefore suitable for tropical regions such as Indonesia. This paper describes the results of a study on paddy field observation based on a correlation analysis between backscatter values of Sentinel-1A data with paddy growth stage observation. Sentinel-1A data from January 2018 to May 2018 were downloaded and processed using SNAP software. The study observed 5 stages: early vegetative (V1), late vegetative (V2), generative (G), Harvest (P), and Land Preparation (PL). An experiment was conducted by collocating the backscatter value of pixels at the location of the paddy growth stage observations, grouping and calculating the frequency for each class and then removing the class that had small frequency. These steps were carried out by way of iterations until the condition was above 5% of the threshold. Classification was performed based on range value obtained from the experiment to create paddy growth stage polygons. Correlation value between backscatter value σ_0 VH and paddy growth stage observation was 0.758. While correlation value between backscatter value σ_0 VV and paddy growth stage observation was 0.537.

Keywords: paddy growth stage, Indramayu, Sentinel, SNAP

1. Introduction

Crop observation is an interesting topic to study using remote sensing technology. Several research related to the use of remote sensing image for crop observation had been done i.e. [1], [2], [3], and [4]. Furthermore, previous researches have stated that the main issue in detecting the stages of paddy growth in tropical regions such as Indonesia is cloud cover. Previous studies by [5], [6], and [7] detected clouds from MODIS satellite image using 1000m spatial resolution visible light spectral band and thermal spectral band. The method of removing the clouds had been done by previous researchers by fusing or cloning images from earlier dates [8] and [9]. This cloud cover factor is quite a significant obstacle, considering that farmers would have started planting paddy during early rainy season and the fast growth rate of paddy itself. Overlaying satellite images at different times will produce data that are biased and inaccurate.



As an alternative, radar-based active remote sensing or Synthetic Aperture Radar (SAR) is capable of detecting through clouds to enable to view objects on the earth surface in any types of weather. The use of satellite radar data to observe crop farming, specifically paddy, has been studied i.e. by [10], [11] and [12]. The result of these researches showed radar intensity capability that was analysed to be applicable for agriculture by detecting rice field area and the polarimetric technique capability in differentiating plant height variety. For rice field mapping, SAR intensity data are particularly well-suited for paddy monitoring since a remarkable increase in backscatter intensity throughout the growth cycle as the paddy grow above water surface and interact with the incident radar signal.

Currently there are several operating radar satellites, one of which is the Sentinel-1 satellite, as the implementation of European Union's Copernicus program. This program will launch around 30 satellites, bringing with them different sensors and different purposes based on its "One Satellite One Mission" principle, designed to support 6 main themes: Atmosphere Monitoring, Marine Environment Monitoring, Land Monitoring, Climate Change, Emergency Management, Security.

Sentinel-1 consists of two C-band SAR satellites, Sentinel-1A and Sentinel-1B, that were designed to primarily address medium to high resolution applications through a main mode of operation that features both a wide swath (250 km), and high geometric (5 m x 20 m) and radiometric resolution [13]. The temporal resolution of Sentinel-1A and Sentinel-1B is 12 days, and 6 days between both satellites, meaning that it is possible to obtain SAR data at one particular location from these satellites every 6 days. This high temporal resolution is highly appropriate to use for activities that require periodic monitoring, such as for agriculture commodity with a lifecycle like paddy.

In general, paddy has a life cycle of 100-210 days and usually divided into three stage: vegetative, ripening, and harvest [14]. This article illustrates an experiment that identified paddy growth stages based on backscatter value as a result of Sentinel-1 Satellite dual polarization data analysis that had been statistically correlated with field observation.

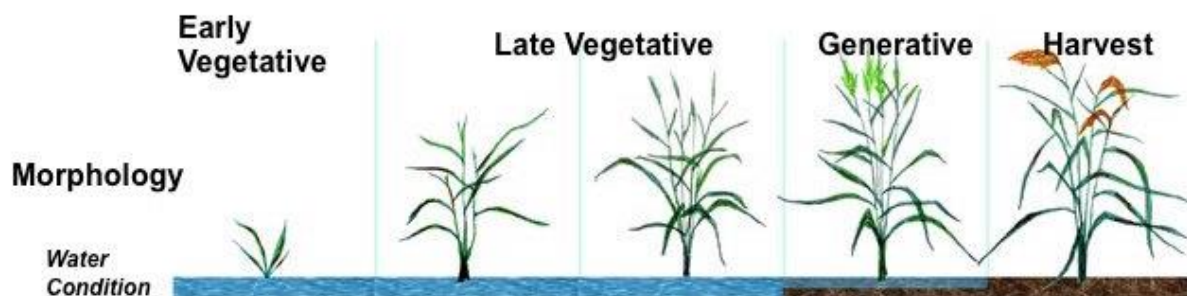


Figure 1. Illustration of Paddy Growth Stages, Modified from [15]

This paper represents an experiment to identify five classes of paddy growth stages: early vegetative stage (V1), late vegetative (V2), ripening or generative (G), harvest (P), and land preparation (PL) based on dual-polarization Sentinel-1 SAR data.

2. Data and Method

The research area was located at Indramayu District, West Java. This location is selected since there is a systematic paddy field observation every last week of each month at a total of 15,066 points observations as listed in Table 1 and illustrated in Figure 2.

Table 1. Paddy Field Observation in Indramayu District

No	Code	Note	Characteristics
1	0	No observation	N/A
2	1	Vegetative Stage 1	Little paddy, much water, space between plants
3	2	Vegetative Stage 2	Growing lush, land is covered

4	3	Generative Stage	Flowering or Malai has grown
5	4	Harvest Stage	Remains of harvest, drying soil
6	5	Puso	N/A
7	6	Land Preparation Stage	Remains of cultivated soil, water puddles
8	7	Field not planted with paddy	N/A
9	8	Not paddy field	N/A

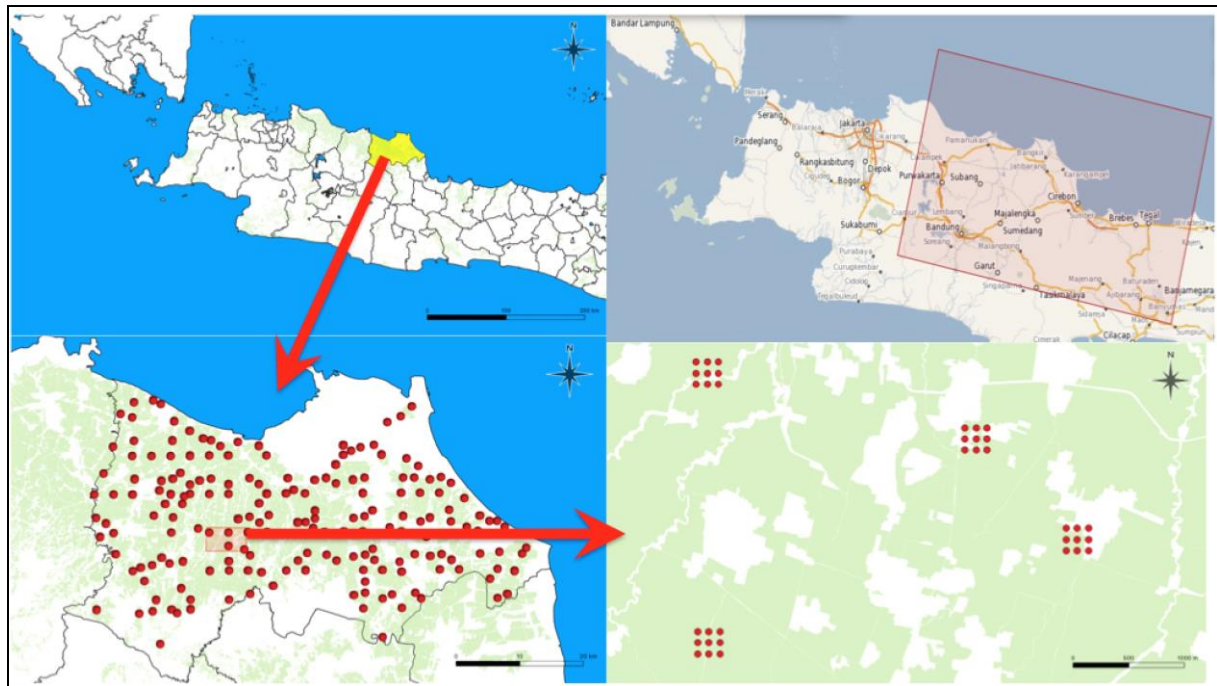


Figure 2. Distribution of 15,066 Paddy Field Observation Points in Indramayu - West Java and Coverage Area of Sentinel-1

This study utilize field observation data from January 2018 to May 2018, and therefore five scenes Sentinel-1 data that cover the region are downloaded from European Space Agency (ESA) data portal (<https://scihub.copernicus.eu/dhus/#/home>) are listed in Table 2. SAR data that used in this study are acquired by Sentinel-1A satellite in descending orbit, interferometric wide (IW) swath mode in high-resolution ground range multi-look detected (GRD) format with spatial resolution approximately 10 meters.

Table 2. SAR Data Sets

Scene ID	Local Time Observation
S1A_IW_GRDH_1SDV_20180127T222521_20180127T222546_020346_022C19_EFBA	January 27th 2018: 05:25 AM, Descending orbit
S1A_IW_GRDH_1SDV_20180220T222521_20180220T222546_020696_023742_0989	February 20th 2018: 05:25 AM, Descending orbit
S1A_IW_GRDH_1SDV_20180328T222521_20180328T222546_021221_0247E7_D2B7	March 28th 2018: 05:25 AM, Descending orbit
S1A_IW_GRDH_1SDV_20180421T222522_20180421T222547_021571_0252D8_415D	April 21st 2018: 05:25 AM, Descending orbit
S1A_IW_GRDH_1SDV_20180527T222524_20180527T222549_022096_026382_E890	May 27th 2018: 05:25 AM, Descending orbit

These data sets are processed by utilizing Sentinel Application Platform Toolbox or SNAP - S1TBX [16] a free open source software (FOSS) to obtain sigma nought for dual polarization (VV and VH). The processing chain consisted of orbit file correction, radiometric calibration, speckle filtering and geometric correction. The result of SAR data processing is backscatter image that contain sigma nought (σ_0) for two polarizations.

The next step is discovering a relation or pattern between sigma nought and field observation as the initial step in classification process. In classifying the current paddy growth stage, a method was used to detect backscatter value changes in each phase. This method directly deleted any outliers in the data that would be processed, and thus the method could be directly used by disregarding the outlier in the data.

Table 3. Example of Data Synchronization Between SAR Backscatter and Field Observation

No.	Point_Name	Latitude	Longitude	PixelX	PixelY	Satellite Date	Sigma0 VH	Sigma0 VV	Growth Stage Code
1	321222102_8	-6.284966	107.987972	3275	4003	2018-01-27	0.0141	0.1058	5
2	321222102_9	-6.284966	107.988870	3285	4003	2018-01-27	0.0225	0.0773	5
3	321218001_7	-6.389630	108.166434	5262	5169	2018-02-20	0.0156	0.0425	8
4	321218001_8	-6.38963	108.167332	5272	5169	2018-02-20	0.0056	0.0308	1
5	321204109_6	-6.622870	107.988164	3277	7765	2018-03-16	0.0411	0.1119	3
6	321204109_7	-6.623768	107.986367	3257	7775	2018-03-16	0.0367	0.2201	5
7	321204112_5	-6.451293	108.127076	4824	5855	2018-04-21	0.0282	0.1137	5
8	321204112_6	-6.451293	108.127974	4834	5855	2018-04-21	0.0342	0.1907	5
...	...	...	...	...	...	...	...	...	...
15068	321202008_9	-6.561119	108.031176	3756	7078	2018-05-27	0.0263	0.0905	7
15069	321202009_1	-6.518359	108.083279	4336	6602	2018-05-27	0.0280	0.1281	2

Outliers are observation that is considered extremely different from most of the data [17]. Data processing using this method was done by way of iteration until the condition was 5% over the threshold. The sigma nought value that has fulfilled its criteria could be seen from January to May 2018, which thus provided the selected sub-segment. Based on the selected sub-segment, a profile of paddy growth stages was made and the correlation of backscatter sigma nought value with field observation value was calculated. By determining the 5% threshold, some classes did not fulfil the requirements, and therefore these classes were omitted and the iteration was repeated based on the new criteria. This process of iteration continued until a condition was reached in which each class had a relative frequency of >5% from the total observation, and the final result is summarized in Table 4.

Table 4. Summary of Iteration and Classification

Iteration	1st	...	5th
N data	2860	...	1720
Min	0.001771	...	0.003022
Max	0.087711	...	0.011472
Average	0.011554	...	0.006687
Range	0.08594	...	0.008449
Number of classes	13	...	12
Class width	0.006611	...	0.000704

	<i>Min</i>	<i>Max</i>	<i>Mean</i>	<i>Frequency</i>	<i>Percentage</i>
Class 1	0.003022	0.003726	0.003374	145	8.430233
Class 2	0.003726	0.004431	0.004079	202	11.74419
Class 3	0.004431	0.005135	0.004783	202	11.74419
Class 4	0.005135	0.005839	0.005487	189	10.98837
Class 5	0.005839	0.006543	0.006191	161	9.360465
Class 6	0.006543	0.007247	0.006895	166	9.651163
Class 7	0.007247	0.007951	0.007599	134	7.790698
Class 8	0.007951	0.008655	0.008303	113	6.569767
Class 9	0.008655	0.009359	0.009007	109	6.337209
Class 10	0.009359	0.010063	0.009711	106	6.162791
Class 11	0.010063	0.010768	0.010415	102	5.930233
Class 12	0.010768	0.011472	0.01112	91	5.290698
				1720	100

Based on classification iteration above, finally the relation between sigma nought range for each polarization with field observation is summarized in Table 5.

Table 5. Summary of Sigma Nought Classification

Code	Type	VH Min	VH Max	VV Min	VV Max
1	Early Vegetative (V1)	0.003022	0.0115	0.0184	0.1157
2	Late Vegetative (V2)	0.01138	0.0246	0.0367	0.1239
3	Generative (G)	0.016036	0.0338	0.0469	0.1085
4	Harvest (P)	0.009658	0.0378	0.0448	0.1338
6	Land Preparation (PL)	0.007398	0.039	0.0448	0.1458

Based on the above references, the spatial groupings of satellite image for each observation month could be calculated using Raster Calculator and Python script. The data above shows existing borderline values that overlapped between one observation phase and another. Identification of these overlapping values required binary code codification for each segmented stage as: not in any stage is set as binary code 0; early vegetative stage is set as binary code 1; late vegetative stage is set as binary code 2; generative stage is set as binary code 4; harvest stage is set as binary code 8; land preparation stage is set as binary code 16; combination between early vegetative stage and late vegetative stage is set as binary code 3; combination between early vegetative stage and generative stage is set as binary code 5; combination between all stages is set as binary code 31.

3. Result and Discussion

Based on the above data analysis, the profile of paddy growth stage showed that the tendency of sigma nought VH and field observation values were better compared to the tendency of sigma nought VV and field observation values. Sigma nought VV value was higher compared to sigma nought VH value in each phase from January to May 2018, as shown in the complexity graphic for paddy growth stage for sigma nought VV and sigma nought VH values.

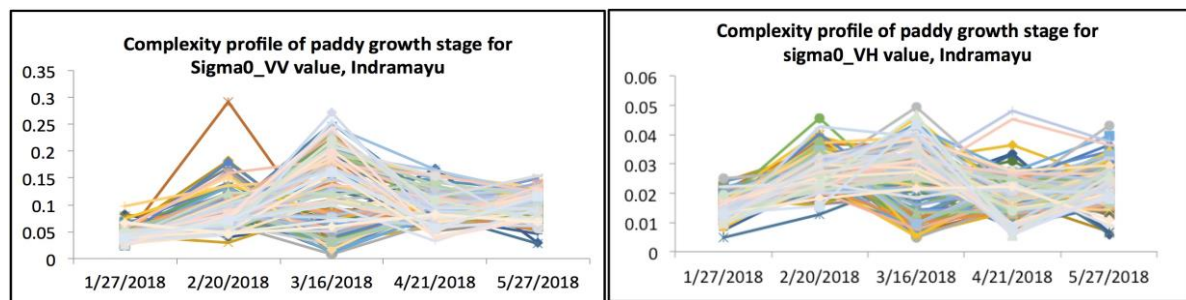


Figure 3. Backscatter of VV and VH from January 2018 to May 2018

After processing spatial classification, the distribution map of paddy growth stage in Indramayu District can be seen in the Figure 4.

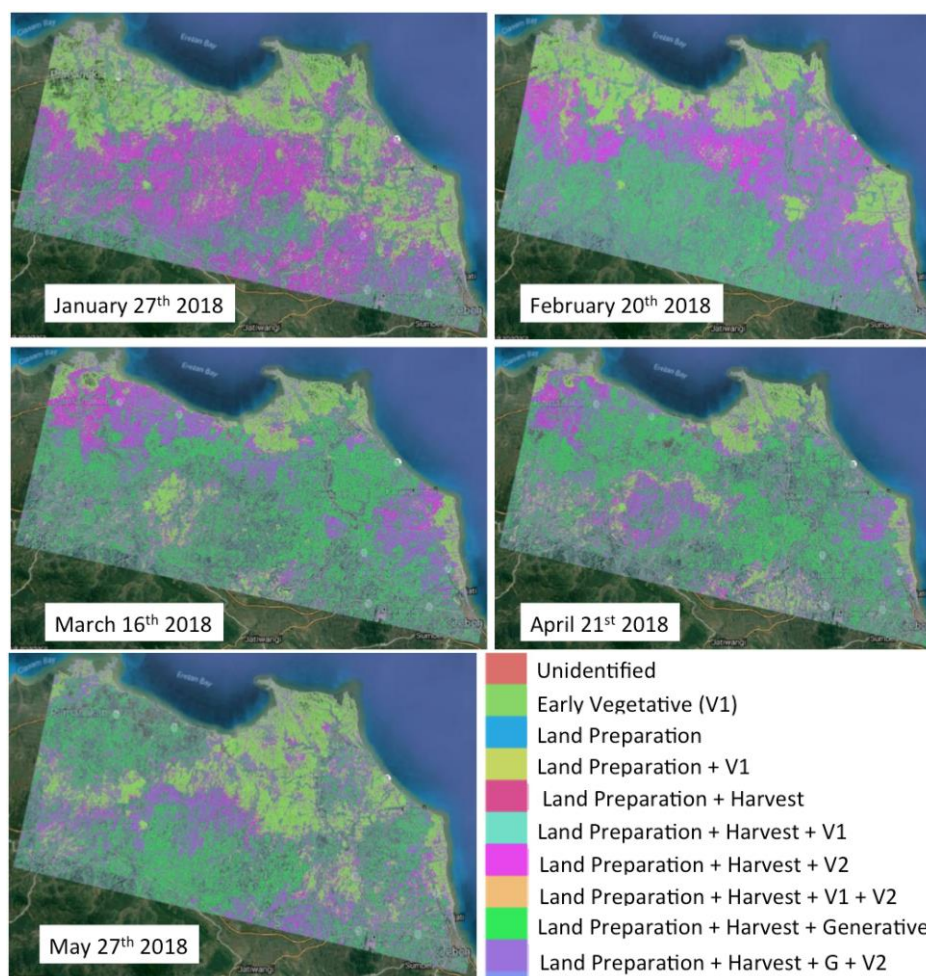


Figure 4. Classification of SAR Image based on Sigma Nought VH polarization for January 2018

By comparing data between months and also assuming that if during n month the paddy was in its early vegetative stage and at month $(n+1)$ it was in its final vegetative stage, the distribution could be analysed and corrected to improve borderline value accuracy of each phase, as illustrated in Figure 4.

It is shown that areas in light green at the northern part of Indramayu District are areas in which farmers had just started planting paddy and thus still in early vegetative stage. If we look at the northern part of Indramayu, the above picture detected paddy at its early vegetative stage while it is actually fishpond. This was caused by the similar characteristics between early vegetative paddy and

fishpond areas. By overlaying this distribution map with a basic map of a paddy field, the differences can be identified more distinctively.

Overlapping values were mostly found in transition areas between one observation stage and another. As an example, the picture below is an illustration of the comparison between early vegetative stage (code 1), land preparation stage (code 16), and overlap between early vegetative stage and land preparation stage (code 17).

Several fishponds were identified by radar image as early vegetative (as shown in the northern part in the above picture). This was due to fishponds having similar characteristics with early vegetative. By overlaying this image with a basic map of the paddy field, better results could be collected on paddy growth stage classification.

4. Conclusions

This research shows the ability of statistical classification of SAR Sentinel-1A data to identify paddy growth stages in Indramayu - West Java. It is found that classification of paddy growth phase based on Sigma nought VH radar satellite image has a narrower span compared to Sigma nought VV radar satellite image. The narrower span eliminated overlapping values between each span value of paddy growth stage and provided data that were relatively not biased.

For several observation stages, there were overlaps from each value span. This was due to similar characteristics of paddy growth stages. As an example, land cultivation stage that was marked by puddles looked similar to the characteristic of early vegetative stage, especially when farmers had just started planting paddy in which the water puddles were more dominant compared to newly planted paddies. Correlation between Sigma nought VV backscatter value and observation of paddy growth phase on the field was 0.537, while the correlation of Sigma nought VH backscatter and observation of paddy growth phase was 0.758.

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