Spatial analysis of rice phenology using Sentinel-1 and Sentinel-2 in Karawang Regency

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Abstract. Karawang Regency is the top rice producer within West Java, Indonesia. Accurate information about the number of harvest area is essential in rice production in Indonesia. The Sentinel imageries (Sentinel-1 and Sentinel-2) which have a spatial resolution of 10 meters can provide spectral information on the earth surface in relatively narrow temporal resolution. The study aims to spatially analyze the rice field phenology using Sentinel-1 and Sentinel-2 imagery and estimate the rice productivity in Karawang Regency. The study used Synthetic Aperture Radar (SAR) Sentinel-1, with the C-Band, which are capable of monitoring rice phenology and Sentinel-2. The combination of polarization from SAR and vegetation index algorithm from the optical image are used to determine the age of rice plants, which then used to estimate rice productivity. The stage of rice was land preparation, vegetative, generative, and harvesting. The result from the estimation of harvest area is between 102,965.00 - 109,338.27 hectares, and the estimation of rice productivity is 5-6 tons/hectares in Karawang Regency.

1. Introduction

West Java province is the largest rice producer in Indonesia, especially Karawang Regency, based on the national statistic report, in 2014-2015, rice production has been reduced based on production [1-3]. The paddy field in Indonesia generally is harvested twice a year in well-irrigated areas and harvested once a year in non-irrigated areas [4]. Karawang Regency is chosen as the study area because it is one of the top rice producers in West Java Province. Northern, Middle, and Southern Karawang areas observed using spatial analysis according to phenology stage of rice filed [3] [2].

Rice field phenology defined as the changes that occur within the rice from the moment rice is planted in the ground and proceeds to grow during the harvesting stage [5]. According to the Agency for the Assessment and Application of Technology Indonesia (BPPT), rice phenology divided into five stages which are land preparation, early vegetative, vegetative stage, generative, and harvesting [6]. The information on rice phenology can assist the rice, planting farmers in their decision-making process, especially in the period where climate change affects the production of rice [7]. Rice crop monitoring is always necessary, but there is a challenge in understanding the dynamics of phenological stages and providing accurate and timely information due to the large farming area [8].

The Sentinel imageries (Sentinel-1 and Sentinel-2) which have a spatial resolution of 10 meters can provide spectral information on the earth surface in relatively narrow temporal resolution. The study aims to spatially analyze the rice field phenology using Sentinel-1 and Sentinel-2 imagery and estimate the rice productivity in Karawang Regency. The study used Synthetic Aperture Radar (SAR) Sentinel-1, with the C-Band, which are capable of monitoring rice phenology. The combination of polarization from SAR and vegetation index algorithm from the optical image are used to determine the age of rice plants, which then used to estimate rice productivity.
2. Methods
This research is focusing on the analysis of the spatial distribution of phenology stage on the paddy field. Karawang Regency chosen as a study area caused it is the top rice producer in Java island, especially in West Java, despite Subang dan Indramayu. The Karawang Regency had a paddy field of more than 80% from total areas. BPS of Karawang Regency in 2018 records the area of paddy fields is > 95,330.5 hectares from the total area of Karawang Regency is 116,332.56 hectares. The paddy field observed in this study planted within a cycle of three main periods, which are planting period, growing period, and harvesting period. Karawang Regency located on 107° 2’-107° 40’ east and 5° 56’-6° 34’ south. It is an administrative region located in the coastal area, adjacent to the Java sea, especially in the north part.

2.2. Image processing
The Karawang Regency had 30 districts with rice field. The rice field observed in this study is rice paddies planted in rice fields with five classes took from these three main periods according to a literature study using backscatter value and index vegetation values, which are land preparation, early vegetative, late vegetative, generative, and harvesting/ripening. The spatial analysis approach is used to achieve a spatial pattern of the rice growth phase, and temporal analysis is used to achieve a temporal pattern of the rice growth phase.

The Synthetic Aperture Radar (SAR) image has been widely used to identify rice phenology due to the capability to provide cloud-free data [9]. The different dual polarimetric SAR image shows similar behavior in rice phenology monitoring[10]. Sentinel-1 polarimetric images in the C-Band are capable of monitoring rice phenology [11]. The research used the Sentinel-1 polarimetric image for identifying the Rice Phenology based on backscatter [12]. The backscatter classification method is used to classify rice phenology according to backscatter values [13].

Moreover, the study aims to spatial analysis pattern of rice phenology and estimation of rice productivity using Sentinel-2A imagery in Karawang Regency. The NDVI algorithm method used to determine the age of rice plants, which then used to estimate rice productivity. The stage of rice was land preparation (NDVI=0.096-0.036), vegetative (NDVI=-0.036-0.24), generative (NDVI=-0.24-0.45) and harvesting (NDVI=-0.45-0.63). This study used NDVI as a tool to differentiate different types of crop. NDVI has widely used in many application, and one of them is for identifying plant characteristics in the ground. NDVI calculated with the following (formula 1).

\[
NDVI = \frac{\rho_{NIR}-\rho_{red}}{\rho_{NIR}+\rho_{red}}
\]  

(1)

Which is \(\rho_{red}\) and \(\rho_{NIR}\) are reflectance value of red and near-infrared bands.

Maximum likelihood classification is then used to classify the Sentinel-1 image into five classes. Reference data, which consists of GPS coordinates and field photos, are used to create training areas of each rice phenology for the maximum likelihood classifier. Each phenology has 1 point with a size of 1 pixel used to create a training area and the total number of points collected in this research are 78 points meaning the number of pixels used to create training areas for both Sentinel-1 images pixels used from previous research.

3. Result and Discussion
The rice field phenology using Sentinel-1 and Sentinel-2 imagery and estimate the rice productivity in Karawang Regency. The rice field phenology was land preparation, early vegetative, late vegetative, generative, and harvesting. The sentinel-1 used data 22 June and 13 November 2017, and The sentinel-2 used data 14 June and 24 July 2017.
The Synthetic Aperture Radar (SAR) Sentinel-1, with the C-Band, which are capable of monitoring rice fielded phenology. Backscatter classification of 22 June and 13 November 2017 Sentinel-1 SAR images produced five classes of rice phenology which are land preparation, early vegetative, late vegetative, generative, and harvesting. The result, based on data processing from backscatter classification of 22 June and 13 November 2017 using Sentinel-1 SAR images, there was five classes of paddy phenology which are land preparation, early vegetative, vegetative, generative, and harvesting. Spatial distribution of paddy phenology in Karawang Regency using Sentinel-1A saw in Figure 1 and Figure 2.

Figure 1 saw phenology on 22 June 2017, the spatial distribution of generative and harvesting stages are dominant around Karawang Regency. The harvesting stages is 57.1%. This spatial distribution of harvesting stages dominant validated that on 22 June 2017 is first growing season in Karawang Regency. Based on Figure 1, the map shows that northern areas of Karawang reach harvesting stage quicker than the central and southern areas of Karawang Regency. Rice field in central areas of Karawang Regency reaches harvesting stage quickest after Northern Karawang. Southern areas of Karawang have rice which reaches the harvesting stage at the slowest rate after northern and middle areas of Karawang Regency.

![Figure 1. Maximum Likelihood classification for rice planting stages on 22 June 2017.](image)

Land preparation phase has the lowest area percentage in Karawang rice field with 14% of the area on 22 June. Harvesting phase during 22 June shows the highest percentage of the area, which is 57% in Karawang rice field. Rice phenology during 13 November 2017 has the lowest area percentage of 17% for late vegetative, and harvesting phase as the highest with 31% of the area. Spatial information on rice phenology in Karawang regency saw in Figure 2. Based on research, Karawang Regency has an irrigation pattern that starts from southern Karawang near Jatiluhur Dam and ends at the northern parts of Karawang Regency. Rice crops in Southern Karawang Regency receive water ahead of middle and northern parts of Karawang Regency.

Figure 2 saw rice filed phenology on 13 November 2017. The spatial distribution of harvesting stages was dominant around Karawang Regency. The harvesting stage with 31.9% area from total area Karawang Regency validated that 13 November 2017.
The vegetative stage (early and vegetative stages) in Karawang Regency is 20.8% of total area, and harvesting stage is 57.1% in Karawang Regency based on data 22 June 2017. Paddy phenology on 13 November 2017 had the vegetative stage with 26.4% and harvesting stage with 31.9% of the area (Table 1).

Table 1. The Backscatter and Phenology Stages on 22 June and 13 November 2017

| Backscatter (dB) | Phenology Stages | Area (Ha) June | Percentage (%) | Area (Ha) November | Percentage (%) |
|-----------------|------------------|----------------|----------------|---------------------|----------------|
| -13.62-12.8     | Land Preparation | 13,227.0       | 12.8           | 19,114.0            | 18.6           |
| -19.4-17.61     | Early vegetative | 14,165.0       | 13.8           | 10,127.0            | 9.9            |
| -17.61-15.6     | Vegetative       | 7,236.0        | 7.0            | 16,955.0            | 16.5           |
| -15.6-13.3      | Generative       | 9,563.0        | 9.3            | 23,657.0            | 23.1           |
| -13.3-11.0      | Harvesting       | 58,774.0       | 57.1           | 32,691.0            | 31.9           |
|                 | Total Area       | 102,965.0      | 100.0          | 102,544.0           | 100.0          |

Source: Data Processing

Spatial distribution of paddy phenology in Karawang Regency using Sentinel-2A processed with NDVI algorithm saws in Figure 4. The figure 3(a) saw paddy phenology on 14 June 2017, and figure 3(b) saw paddy phenology on 24 July 2017. Figure 4(a) saw the spatial distribution of vegetative stages are dominant around Karawang Regency with 66.7%. This spatial distribution of vegetative stages dominant validated that on 14 June 2017 is first growing season in Karawang Regency. The second image (Figure 4(b)) saw phenology on 24 July 2017, the spatial distribution of vegetative stages are dominant around Karawang Regency. The vegetative stage with 77.1% area from total area Karawang Regency validated that 24 July 2017 is still in first growing seasons in a paddy field in Karawang Regency.
Figure 3. The paddy phenology on (a) 14 June 2017 and (b) 24 July 2017 in Karawang Regency.

The vegetative stage area in Karawang Regency on 14 June was 66.7% of the total area, and harvesting stages is 6.4%. Paddy phenology on 24 July 2017 had the vegetative stage with 77.1%, and harvesting stage is 0% of the total area in the Karawang Regency (Table 2).

Table 2. The Area of NDVI and Rice Phenology on 14 June and 24 July 2017

| NDVI   | Phenology          | Area (Ha) June | Percentage (%) | Area (Ha) July | Percentage (%) |
|--------|--------------------|----------------|----------------|----------------|----------------|
| 0.096-0.036 | Land Preparation | 6,114.98        | 5.6            | 15,973.56      | 14.6           |
| 0.036-0.240 | Early vegetative  | 44,560.09       | 40.8           | 59,507.50      | 54.4           |
| 0.240-0.450 | Vegetative        | 28,376.57       | 26.0           | 24,785.00      | 22.7           |
| 0.450-0.630 | Generative       | 23,335.85       | 21.3           | 9,077.92       | 8.3            |
| 0.450-0.630 | Harvesting       | 6,950.78        | 6.4            | 0              | 0.0            |
| Total Area |                   | 109,338.27      | 100.0          | 109,338.27     | 100.0          |

Source: Data Processing

4. Conclusions
The stage of rice was land preparation, vegetative, generative, and harvesting. The result from the estimation of harvest area is between 102,965.00 - 109,338.27 hectares, and the estimation of rice productivity is 5-6 tons/hectares in Karawang Regency.
5. Acknowledgments
Authors wishing to acknowledge support from the Ministry of Research and Higher Education, under the Penelitian Dasar Unggulan Perguruan Tinggi (PDT) or the Basic Primary Research for Higher Education Grant based on contract no: 382/UN2.R3.1/HKP.05.00/2018.

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