Model of paddy rice phenology using Sentinel 2-A imagery with NDVI algorithm in Subang Regency

E A P Lestari, Supriatna and A Damayanti
Department of Geography, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia
Corresponding author's email: ysupri@sci.ui.ac.id

Abstract. Rice is a basic need for most Indonesians. Subang Regency is one of the food districts in West Java with high paddy rice production. Fluctuation in the value of paddy rice production over the past five years makes production conditions uncertain and difficult to predict. Monitoring the condition of paddy rice fields over a short period of time would improve crop size prediction. This study aims to explain the paddy rice phenology using Sentinel 2-A imagery with NDVI (Normalized Difference Vegetation Index) algorithm in Subang Regency. The benefit of this study is to monitor the paddy rice phenology using remote sensing technology. Greenness values were recorded from Sentinel 2-A temporal 10 daily images with NDVI algorithm. Greenness values will be analysed descriptively according to CCTV recording on paddy rice fields. Based on the greenness value, NDVI can determine the beginning of the planting period and the end of the paddy rice planting period. The results show that Sentinel 2-A imagery can monitor the paddy rice phenology by measuring the value of NDVI vegetation index. The development of remote sensing technology can be used for estimating paddy rice phenology over short periods of time.

Keywords: NDVI algorithm, paddy rice phenology, Sentinel 2-A imagery

1. Introduction
Paddy rice stands as one of the most important food crops supplying 20 % of the world’s calorie supply [1]. The paddy rice crop is extensively grown in various landscapes and climate such as the tropics, sub-tropics and temperate regions found both in upland and lowland terrain [2]. Paddy rice is a staple food for most Indonesians [3]. Human population growth across the globe especially in the developing countries require the ever-growing demand for paddy rice as their daily diet at the same time. In order to meet the demand, various efforts have been made over the years[4]. In correlation with rice production, uncertainty about the volume of paddy rice production can be reduced using remote sensing technology to estimate production conditions.

Remote Sensing is the observation of an object using a device remotely [5]. Some studies have proved that the determination of paddy rice phenology can be monitored with satellite image technology such as Sentinel 2-A imagery [6-8]. The satellite, which is planned to last for 7 years, has 4 spectral bands at 10 meters spatial resolution, 6 bands at 20 meters spatial resolution (four of which are for spectral vegetation) and 3 spectral bands at a spatial resolution of 60 meters [9]. Thus, the Sentinel-2 image could be used in the classification of paddy rice field cover.
The existence of vegetation can be detected using remote sensing by looking at the value of the vegetation index developed based on three channel feature spaces, which are green, red and near-infrared [10]. The paddy rice field cover normally shows the greenish value reflected by its reflectance value. In the other hand, NDVI algorithm is a scaled non-linear transform of the simple ratio (SR = NIR/red). It was initially promoted in over sparsely vegetated region to enhance the vegetation signal [11]. By analysing the condition of vegetation, the NDVI algorithm can determine the paddy rice growth phase by knowing the value of stretching NDVI [12]. In connection with that, the paddy rice plants phenology can be grouped into 3 categories, which are the water phase, the vegetative phase, and the generative phase [13]. Paddy rice is in its most reproductive stage after heading and NDVI values decrease again to its minimum value at the time of the harvest [14].

In this case study, during the 2014, the productivity of lowland paddy rice in Subang Regency was 51.30 kw/ha. While in 2015, the productivity of wetland paddy rice in Subang Regency was increased to 62.43 kw/ha [15]. Paddy rice productivity that has fluctuated in the regency can be overcome by using remote sensing technology to monitor the paddy rice phenology. The purpose of this study was to determine the paddy rice phenology using Sentinel 2-A imagery with greenness value NDVI algorithm in Compreng District (Subang Regency) to determine the beginning and the end of the paddy rice planting period.

2. Method
The study area is in Compreng Sub-district, Subang Regency, West Java, Indonesia, at 6°41’10’’S latitude and 107°33’10’’ E longitude. The main variable used is the paddy rice phenology, which is characterized by the parameters of NDVI value and age of paddy rice plant (week). The data collection was started by downloading United States Geological Survey (USGS) Sentinel Image 2 level 1-A 48 MZT Code with the record of second planting period in the region from January to May 2017.

2.1. Geometric, radiometric and atmospheric correction
Level 1-C Sentinel 2-A means that this image has been corrected geometrically and radiometrically in the form of Top of Atmospheric (ToA) reflectance values [10]. Geometric correction aims to correct errors that is caused by satellite movements and sensors when orbiting. Radiometric correction aims to change the Digital Number (DN) to radians of ToA or reflectance using parameters available in the image metadata. This would calculate the reflectance value to perform the atmospheric correction. Atmospheric correction for Sentinel 2-A imagery uses a sensor plug-in in ESA SNAP 5.

2.2. NDVI algorithm
Paddy rice phenology has a stretch of NDVI values and each planting age [13]. As one of the most commonly used vegetation indices, the NDVI algorithm shows a greenish index of vegetation or photosynthetic activity of vegetation [14]. NDVI Algorithm can determine the paddy rice growth phase by analysing the value of stretching NDVI. The range of NDVI values are from -1 to +1. For NDVI formulas can be seen in the following formula [12].

\[
\text{NDVI} = \frac{\text{NIR (Near – Infrared Radiation) Band} - \text{Red Band}}{\text{NIR (Near – Infrared Radiation) Band} + \text{Red Band}}
\]  

(1)

The value of NDVI stretching in the paddy rice phenology can be seen in table 1.

2.3. Paddy rice phenology
Paddy rice phenology was obtained based on the results of Sentinel 2-A image processing using NDVI algorithm. The results of data processing were then analysed spatially based on the distribution of paddy rice phenology. It will show each NDVI values for each month later.
Table 1. The range of NDVI values for the ages of paddy rice plant and phases.

| No. | NDVI values   | Vegetation density | Age of paddy rice plant (week) | Phase                  |
|-----|---------------|--------------------|--------------------------------|------------------------|
| 1   | -0.096–0.036  | Non-vegetation/water| < 3                            | Water                  |
| 2   | 0.036–0.240   | Very low           | 3 – < 4                        | The beginning of vegetation |
| 3   | 0.240–0.456   | Low                | 4–6                            | The first phase of vegetation |
| 4   | 0.456–0.652   | Medium             | 6–8                            | The second phase of vegetation |
| 5   | 0.652–0.884   | High               | 8–13                           | The last phase of vegetation |

After the optimum vegetation is reached, the NDVI values will decrease according to the grain maturity level.

2.4. Paddy rice plant patterns in Compreng Sub-district 2017

Data processing were analysed spatially based on the pattern of paddy rice planting time in the study area. Paddy rice planting time matrix was then built based on the paddy rice phenology. The direction of the watershed flow was also determined to produce a pattern of paddy rice planting time in the study area.

3. Results and discussion

3.1. Paddy rice phenology with NDVI algorithm in Compreng Sub-District, Subang regency

Figure 1 shows that each NDVI value each month is different. This is caused by the difference chlorophyll of each paddy rice plant. The results of processing the Sentinel 2-A Image proves that the stretching of NDVI values can determine the different paddy rice phenology in Compreng District, Subang Regency. To get a different paddy rice phenology in the same stretch of NDVI value, we can see the phase that occurred in the previous month.

Paddy rice phenology is produced from NDVI Algorithm and age of paddy rice plant as shown in table 2. The water phase obtained NDVI value of -0.008737 which is in the range of -0.096 to 0.036 NDVI stretching value transformed it to a planting age of < 3 weeks. In the stretching value of 0.036–0.24 NDVI has an NDVI value of 0.176644 (the beginning of the vegetative phase). In the NDVI 0.24–0.456 stretching value has 2 different phases. These values are 0.326946 (the first phase of vegetative) and 0.431121 (the last phase of generative). In the stretching NDVI value of 0.456–0.652 there are two different phases. These values are 0.628374 (the second phase of vegetative) and 0.539653 (the beginning of the generative phase). The optimum/last phase of vegetative has a value of NDVI 0.652–0.884 stretching value that is equal to 0.719823.

3.2. Distribution of paddy rice phenology in Compreng Sub-district, Subang regency

Sentinel 2-A image processing proves that the stretching of NDVI values can determine the different paddy rice phenology in Compreng Subdistrict, Subang Regency (figure 2). The distribution of paddy rice phenology follows the irrigation flow originating from the Jatiluhur Reservoir. The flow of irrigation starts from the upstream to the middle part, then to the downstream. This impacts the upstream part earliest paddy rice plantation phase.

On January 12, rice phenology in the north to the south is the difference. In the north part was dominated by the water phase and the beginning of the vegetative phase. In the middle part was dominated by the first phase of vegetative and the second phase of vegetative. While in the south part was dominated by the last phase of vegetative.

On March 13, getting to the south, rice phenology was getting ripe. In the north part was dominated by the first phase of vegetative and the second phase of vegetative. In the middle part was dominated
by the last phase of vegetative. In the south part was dominated by the beginning of the generative phase and the last phase of generative.

On April 2, getting to the south, rice phenology was getting younger. In the north part was dominated by the beginning of the generative phase. In the middle part was dominated by the last phase of vegetative, the beginning of the generative phase, and the last phase of generative respectively. While in the south part was dominated by the beginning of the vegetative phase.

On May 7, getting to the south, rice phenology was getting younger also. In the north part, it was dominated by the last phase of generative. In the middle part was dominated by the beginning of the generative phase. In the south part was dominated by the beginning of the generative phase and the first phase of vegetative.

3.3. Paddy rice plant patterns in Compreng Sub-district 2017

Based on table 3, paddy rice planting patterns in Compreng Subdistrict follow the irrigation flow that starts at the upstream so that the upstream part experiences the first planting time. In January Decade II, the Upstream was dominated by the second phase of vegetative and the last phase of vegetative. The middle-stream was dominated by the beginning of vegetative phase, the first phase of vegetative, and the second phase of vegetative. The downstream was dominated by water and the beginning of

![Figure 1. NDVI values in Compreng Sub-district.](image)

| No. | NDVI Values | Age of paddy rice plant (MST) | Phase                        |
|-----|-------------|--------------------------------|------------------------------|
| 1.  | -0.008737   | < 3                            | Water                        |
| 2.  | 0.176644    | 3 – < 4                        | The beginning of Vegetative Phase |
| 3.  | 0.326946    | 4–6                            | The first Phase of Vegetative |
| 4.  | 0.628374    | 6–8                            | The second Phase of Vegetative |
| 5.  | 0.719823    | 8–13                           | The optimum / last phase of vegetative |
| 6.  | 0.539653    | 13–16                          | The beginning of Generative Phase |
| 7.  | 0.431121    | >16                            | The last Phase of Generative  |
Figure 2. Paddy rice phenology in Compreng sub-district.

| Irrigation flow planting time | Upstream | Middle-stream | Downstream |
|-------------------------------|----------|---------------|------------|
| January Decade II             | The second phase of vegetative and the last phase of vegetative | The beginning of the vegetative phase, the first phase of vegetative, second phase of vegetative | Water and the beginning of vegetative phase |
| March Decade II               | The beginning of Generative phase and the last phase of generative | The second phase of vegetative and the last phase of vegetative | The first phase of vegetative, the second phase of vegetative and the last phase of vegetative |
| April Decade I                | The beginning of vegetative phase | The beginning of the generative phase and the last phase of generative | The last phase of vegetative and the beginning of generative phase |
| May Decade I                  | The beginning of vegetative phase and the first phase of vegetative | The beginning of the generative phase and the last phase of generative | The beginning of the generative phase, the last phase of generative and the second phase of vegetative |
vegetative phase. In March Decade II, the upstream area was dominated by the beginning of generative phase and the last phase of generative. The middle-stream was dominated by the second phase of vegetative and the last phase of vegetative. Then, the downstream was dominated by the first phase of vegetative, the second phase of vegetative and the last phase of vegetative. In April Decade I, the upstream was dominated by Beginning of Vegetative phase. The middle-stream was dominated by the beginning of generative phase and the last phase of generative. The downstream was dominated by the last phase of vegetative and the beginning of generative phase. In May Decade I, the upstream was dominated by the beginning of the vegetative phase and the first phase of vegetative. The middle-stream was dominated by the beginning of generative phase and the last phase of generative. The downstream was dominated by the beginning of generative phase, the last phase of generative, and the second phase of vegetative. Thus, the time of paddy rice planting in Compreng Subdistrict begins at the upstream part, to the middle part, then to the downstream respectively.

4. Conclusion
Utilization of Sentinel Image 2-A can be used for estimating the paddy rice phenology. Based on the greenness value of NDVI, the beginning of the planting period and the end of the paddy rice planting period can be determined, which enables us to determine the paddy rice phenology. The higher the NDVI value, the higher the chlorophyll in the vegetation, meaning that it can reach the optimum vegetative phase. On the other side, the paddy rice cropping pattern in Compreng Subdistrict follows the irrigation flow in the Watershed starting from the upstream part, to the middle part, then to the downstream area. Thus, the paddy phenology can effectively determine paddy rice planting patterns in Compreng Sub-district.

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