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SPATIAL ANALYSIS OF RICE PHENOLOGY USING SENTINEL 2 AND UAV IN PARAKANSALAK, SUKABUMI DISTRICT, INDONESIA

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ABSTRACT: West Java is the third province with the largest area of paddy field. On the province scale, there are five districts with more than 60,000 hectares of the paddy field area. Sukabumi is the fifth largest district, with 6.8 percent of the area covered with paddy field. Although it is not the greatest number, Sukabumi is the largest producer of paddy with more than 6 tons per hectare, especially in 2015. Rice is the primary food for most Indonesian. Therefore, monitoring the rice planting regarding the phenology, planting area, and productivity is a critical process. Information from the process is very important to address the national issues on food security. This study uses the excellence of remote sensing technology to cover a big area of paddy field in Sukabumi. The images from Sentinel 2 and Unmanned Aerial Vehicle (UAV) are utilized to generate the Normalized Difference Vegetation Index (NDVI). The objectives of this study are two folds: (i) to create NDVI map from both Sentinel 2 and UAV; and (ii) to analyze rice crop phenology from the NDVI value. With NDVI, this study can determine the growth stage of paddy by discriminating each stage based on the spectral value. The planting phases that have discovered in the area are divided into land preparation, vegetative, generative, and harvesting. Based on the NDVI value, it is known that the vegetative stage ranges from 0.18 to 0.80. The study concludes that results from both Sentinel 2 and UAV can be used to show the distribution of paddy based on different growth stages.

Keywords: Rice crop phenology, Sentinel 2, UAV, Vegetation index, Spatial analysis

1. INTRODUCTION

Spatial data have played an important role in recent times. As the product of the spatial data, maps provide many services, from planning routes to the scientific analysis of a very critical issue [1]. There are long-range applications that need accurate and timely spatial data. One of the critical issues in Indonesia that need to be addressed with accurate and timely spatial data is food security [2]. Food security is a critical issue in the agricultural sector that has not yet been resolved. Transformation on the agricultural land and the growing number of population has been the main challenges facing by the Indonesian government to secure food for the people [3].

According to Indonesian National Statistics (or known as Badan Pusat Statistik) 2015, about 51.69 percent of the national rice production produced on Java island. Statistically, West Java Province is the third-largest area with paddy field after East and Central Java Province. The paddy field area reached 912,794 hectares in 2015 [4]. On the provincial scale, there are five districts, including Indramayu, Karawang, Subang, Cianjur, and Sukabumi, with more than 60,000 hectares of the paddy field area. In 2015, Sukabumi was the fifth largest district with 6.8 percent of the area covered with paddy field [5]. Sukabumi also became the fifth largest district in terms of harvested paddy fields, with more than 125,000 hectares harvested in 2015. From productivity-wise, Sukabumi district is in the ninth rank, with more than 60 tons per hectare in 2015 [6].

On the other hand, statistical data also showed that in the last ten years, the population of Java island increased by 1.15 percent, with a decrease in the rate of the natural land area by 0.02 percent per year. In terms of food security, Sukabumi district has more than five percent of the province population. Among the districts with the largest paddy field, Sukabumi has the second largest population with more than 2.4 million people, especially in 2017 [6].

There are two types of paddy fields in Indonesia, irrigated and non-irrigated (rain-fed). Rice can be harvested twice in irrigated field and once in non-irrigated field. Normally, there are three phases of rice crop growing stages in one planting season, which are vegetative, reproductive, and ripening [7]. Paddy usually planted up to 90 days in irrigated field, and up to 130 days in non-irrigated (rain-fed) field. Before rice seedlings planted, rice fields will be flooded with plenty of water. Once the seeds are planted or in the germination phase, it takes 25-30 days to reach the initiation stage of the saplings, and the rice leaves begin to grow [8]. The leaf color will transforms from yellow to green in the early phase of the saplings and intermediate stripping phase.

The reproductive phase is when the plant was growing, started from flowering until the maturation period (harvest). The growth will reach maximum on the initiation of the flowering, which usually takes 55 to 75 days depends on a certain crop variety [8]. The next stage is the ripening phase, where the flower of the rice begins to grow, and the leaves start to turn yellow. For a certain rice variety, this phase takes up to 85-115 days [8]. The last stage is when the paddy is about to be harvested. This is the stage where rice is developed and ready to harvest.

From the statistical data, it is known that Sukabumi district is not the greatest producer of rice. Although it has a large area of paddy, productivity is relatively less than other "rice-producer" districts. Nevertheless, Sukabumi has a great number of its population. If this condition continues, this area is potentially threatened by the food inadequacy and will forced to supply the demanded rice from another area.

The monitoring the rice planting regarding the phenology, planting area, and productivity is a critical process to tackle the food security issues. This study is conducted in Sukabumi, to produce baseline information for agricultural monitoring program in the area. Sukabumi has 66,692 hectares of paddy field [6]. It is a heavy task to observe the whole area. Therefore, this study uses the excellence of remote sensing technology that is able to provide spatial data for a relatively large area and provide multi-temporal information for multi-temporal analysis [2]. The multi-spectral sensor of remote sensing satellite is also sensitive to visible light, and infrared energy makes it very useful to highlight specific information of the earth object, like plant greenness index [9], soil wetness index [10], and land surface temperature [11]. With the development of recent technology, the remote sensing system is available on various platforms, from the conventional satellite and airborne to the Unmanned Aerial Vehicle (UAV) or drones.

Remote sensing technology is utilizing electromagnetic (EM) spectrums to collect information about the earth surface. Each earth objects has a unique reponse to a certain EM. Spesifically, vegetation has the highest percentage of reflectance on near-infrared spectrum. Vegetation will reflects up to 50 percent of the incidental EM spectrum, particularly on 0.7 to 1.3 μm [12]. The reflectance will vary due to different plant bio-physical characteristics. By utilizing that specific portion of the EM spectrum, remote sensing technology enables us to diffirentiate plant species [12], plant age [13], and plant health [14]. The vegetation index (VI) is a value that can describes those plant attributes.

The Normalized Difference Vegetation Index (NDVI) is the most widely used VI algorithm which sensitive and can be associated with plant attributes [15]. The NDVI has been used by many studies to estimate vegetation biomass [16-18], measure plant health [19], and analyze plant phenology [20, 21]. Based on those previous works, this study aims to generate NDVI map from both Sentinel 2 and UAV and to analyze rice crop phenology from the NDVI value.

2. METHODS

This study utilizes medium- and high- resolution multi-spectral imageries and photos to create vegetation index and applied the VI to differentiate paddy based on the crop stages or phenology. Sentinel 2 is a high-resolution multi-spectral imagery that has been widely used to map crop phenology [22, 23]. The previous works benefited from a narrow satellite's revisit frequency, which is five days between two satellite orbits (Sentinel 2A and 2B). It is capable in providing daily information which very suitable in agricultural monitoring projects. UAV system will support very high-resolution photos that is important to produce data in higher accuracy.

2.1 Study Area

This study located in Parakansalak. It is a sub-district within Sukabumi, which absolutely located between 106º39'51.84" and 106º44'24" east, and 6º44'34.08" and 6º49'40" south. It is 61 kilometers from Sukabumi capital city, Pelabuhan Ratu and close to the peak area of the Mt. Salak (Fig.1).

Statistically, the area of crop field in Parakansalak is only 1.07 percent (716 hectares) from the total crop field of Sukabumi, with the land productivity reached 6 tons per hectare in 2017. The number is relatively low, however the crop fields are found from 200 to 700 meters above mean sea level.

2.2 Image Acquisition

2.2.1 Sentinel 2

Sentinel 2 is a product of imminent collaboration between European Space Agency (ESA), European Commission, and their stakeholders. It is part of the Copernicus program by the European Commission (https://www.esa.int/). The system has two orbiting satellites, Sentinel 2A and 2B. The Sentinel 2A has been operated since 2015, while Sentinel 2B launched on 2017. The Sentinel Multi Spectral Instrument (MSI) consists of 13 spectral bands in three different spatial resolutions. It has four bands at 10 meters, six bands at 20 meters, and three bands at 60 meters spatial resolution. This study used six tiles of Sentinel 2 acquired from April to September

2017, which cloud cover are less than 50 percent (Table 1). The imageries collected from Copernicus open access hub (https://scihub.copernicus.eu/).

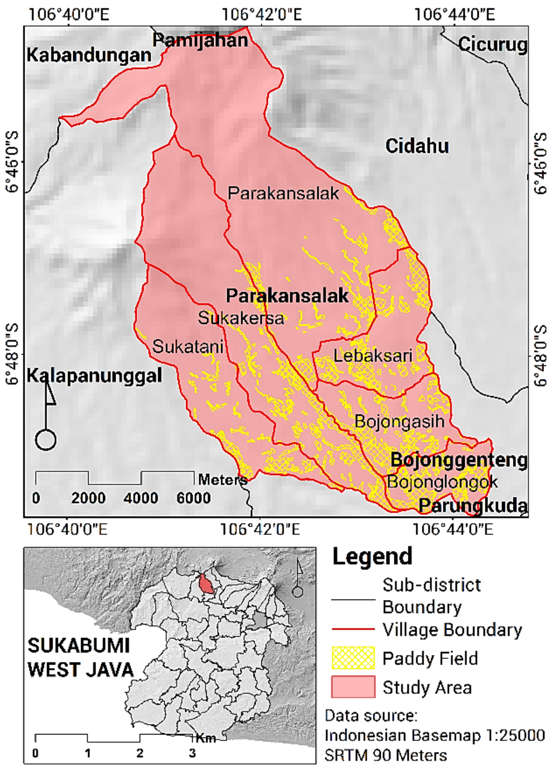

Fig.1 Study area located in Parakansalak sub-district, Sukabumi, West Java province

2.2.2 Unmanned Aerial Vehicle (UAV)

This study used a quadrotor DJI Phantom 4 as the UAV platform. The UAV equipped with a lightweight (72 grams) Parrot Sequoia, a multi-spectral sensor with four spectral bands green, red, red-edge, and near-infrared. The sensors have 1.2 megapixels global shutter camera and in pairs with Sunshine sensor, which operates in the same spectrum bands and able to calibrate the different light conditions [24].

This study considers several things in accordance with image acquisition. First, the flight plans set in four different area of paddy field using Pix4d software (Fig 2). The flight plans are covering around 74 hectares. Second, altitude and image overlap need to be adjusted because it will determine the image resolution and the quality of the photos. Overlapping will determines the quality of the image, especially when creating a digital elevation model [2].

Photo from UAV were acquired in May 2017. A total of 34 sample locations were recorded during the field visit. The field data collection was focused on gathering primary data such as crop growth stage, field photos, and ground control points. The sample distributions are following previous study [2], therefore this study also found similar crop types in the surrounding area. The distribution of sample locations showed in Fig 3.

Table 1 Sentinel 2 imageries used in this study

Entity ID	Acquisition Date	Cloud Cover (%)
T48MXT_A009467_ 20170415T082300	15 April 2017	44.39
T48MXT_A009753_ 20170505T082330	5 May 2017	12.43
T48MXT_A010325_ 20170614T083811	14 June 2017	19.55
T48MXT_A010611_ 20170704T031454	4 July 2017	3.27
T48MXT_A002203_ 20170808T082114	8 August 2017	0.26
T48MXT_A011755_ 20170922T031450	22 September 2017	11.56

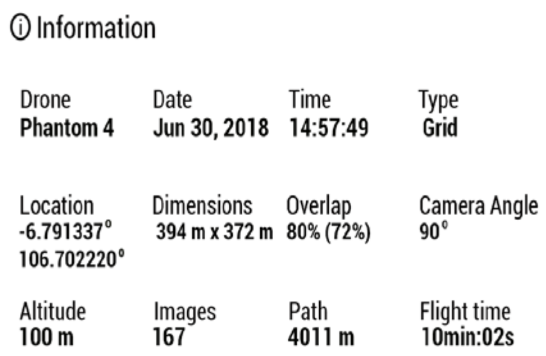

Fig.2 The flight plans, altitude, and image overlap settings in Pix4D software

2.3 Normalized Difference Vegetation Index (NDVI)

The multi-spectral bands are combined for generating various vegetation indices. The raster data is being clipped with paddy field polygons prior to the analysis. Particularly, this study is using NDVI to discriminate different crop growth stages. Previous study has showed some NDVI application on crop phenological assessment [25]. The mathematical model for NDVI are as follows [26]:

$$NDVI = \frac{\rho NIR - \rho red}{\rho NIR + \rho red} \quad (1)$$

where ρred and ρNIR are reflectance value of red and near-infrared bands.

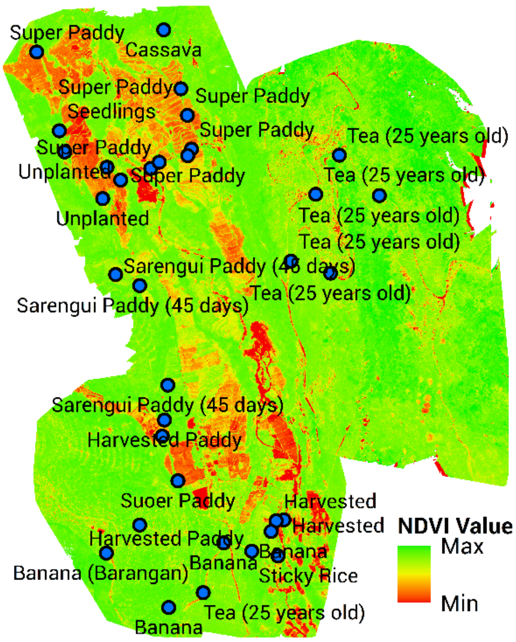

Fig.3 The distribution of sample locations in this study [2]

3. RESULTS AND DISCUSSIONS

3.1 NDVI Derived from Sentinel 2 Imageries

As mentioned previously, the NDVI value have been extracted from Sentinel 2 imageries and UAV photos. Particularly, NDVI from each Sentinel 2 imagery is showing similar value, especially for the maximum NDVI. The highest maximum NDVI were found in May 2017, with value reached 0.9 (Fig 4; Table 2). The value is significantly different, because in the other months (except May) maximum NDVI value were averagely found at 0.76 (Table 2). The lowest minimum NDVI were also found in May 2017 with value reached -0.15 (Fig 4; Table 2). Fig 4 is showing the change of NDVI value each month. From April to September, it is clearly seen that the color start to change, the red area (low NDVI) are gradually changing into green, and gradually changing back into red within the period of three or four months (Fig 4).

Table 2 Minimum, maximum, and mean NDVI from April to September 2017

NDVI	Month					
	4	5	6	7	8	9
Min	-0.03	-0.15	0.00	0.02	0.02	-0.04
Max	0.76	0.90	0.77	0.78	0.79	0.73
Mean	0.50	0.55	0.47	0.56	0.50	0.42

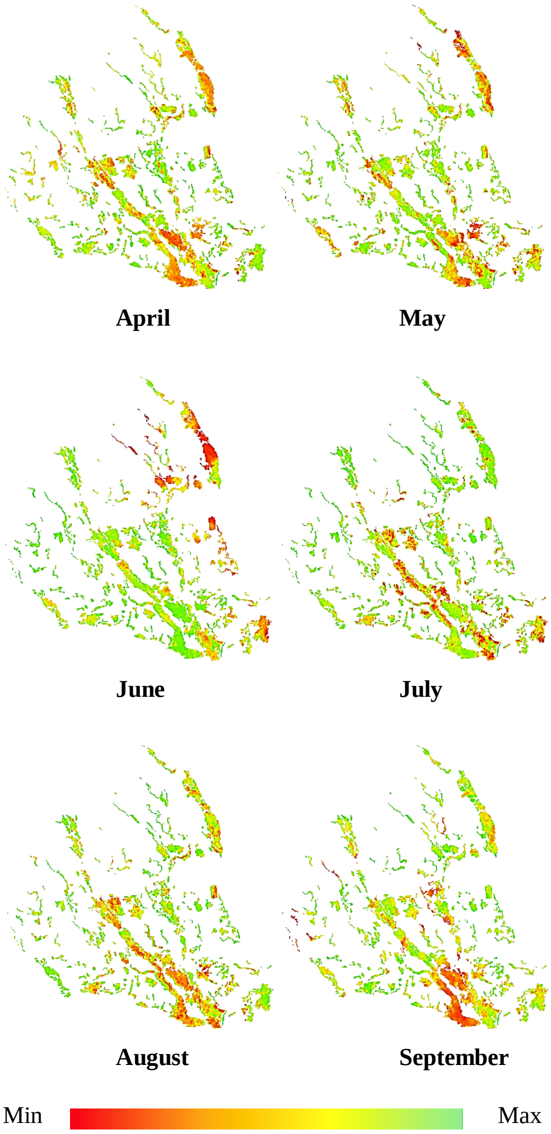

Fig.4 Changes in NDVI value from April to September 2017

3.2 NDVI Derived from Multi-spectral UAV Photos

Similar with previous process, the raster data from UAV are being clipped with paddy field polygon data. Considering extensive coverage of the study area, UAV photos only covers small portion of the area and only available for May due to the technical problems. Nevertheless, the photos still can be compared with results from satellite imagery.

The NDVI value ranged from -0.25 to 0.98, with the average value reached 0.60 (Fig 5). It is closely related with the value from satellite imagery. The low NDVI values are indicating the post-harvest land, while high NDVI values are showing the reproductive stages of the crop.

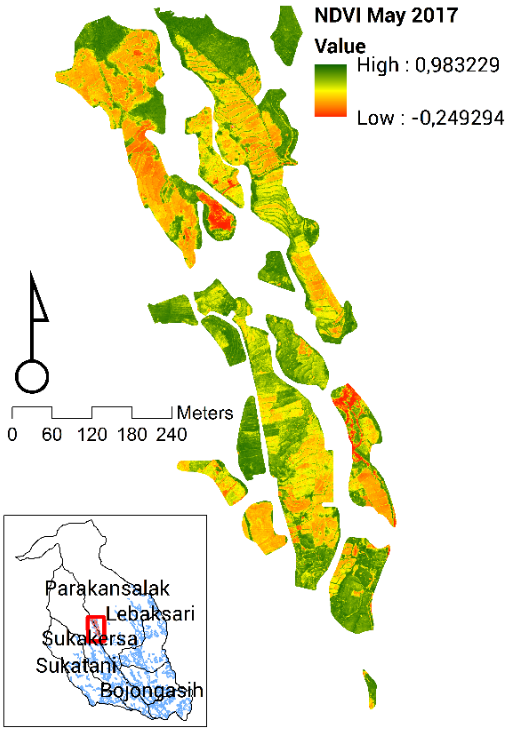

Fig.6 NDVI value in May 2017 from UAV photos

3.3 Rice Crop Phenology

The NDVI values are associating with the crop age. Previous studies have confirmed the relationship between crop growing stages and NDVI value [22-23, 25]. The relationship occurred in a "parabolic" model. The early stages of crop will have low NDVI value (Fig 7 and 8). The value is increasing as the crop grows older. It will reach a certain value as the peak and gradually decreased as the crops are about to be harvested.

Fig 7 shows an example of relationship between crop growing stages and NDVI value. In July, most area are in blue color, indicates that rice has planted and were in the reproductive stage. As the month changes, the color turned into a brighter blue or green, indicates that rice has entered the ripening stage. In the ripening stage, the leaf transforms from green to yellow and chlorophyll concentration decreases, creates a lower NDVI values. This condition occurred in 90 days rice crop.

4. CONCLUSION

The multispectral sensor from Sentinel 2 and UAV platform has been successfully applied to generate NDVI. The NDVI has been helpful in image separation process, discriminating different stages of paddy. However, the NDVI values are still vary. Some different types of crop might have similar NDVI values. Therefore, future works is needed, especially to measure spectral value of different vegetation using spectroradiometer and use it to verify the result from NDVI.

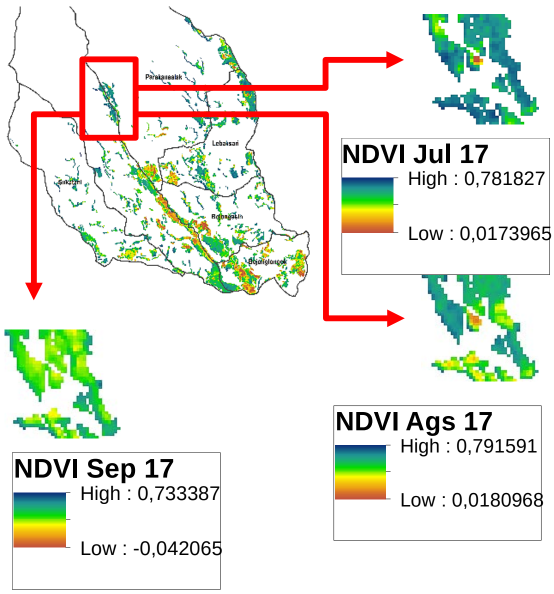

Fig.7 Changes in NDVI value are indicating changes in crop growing stages

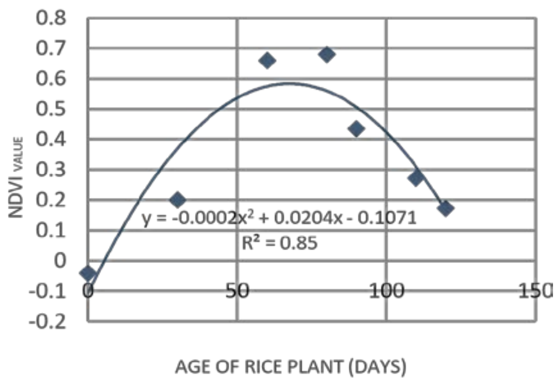

Fig.8 The "parabolic" type relationship between NDVI and crop growing stages

5. ACKNOWLEDGEMENTS

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