Estimation of rice productivity using Sentinel-2 imagery with NDVI algorithm in Cariu sub-district, Bogor, West Java

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Abstract. Cariu Sub-District is one of the leading rice producers in Bogor Regency, West Java, Indonesia and in a population of 45,921 in 2017 with a population growth rate of 0.64% based on projection results. The consequence of the increasing population growth rate is increasing rice consumption. Cariu Sub-District has not been able to self-sufficient food. In 2017, Cariu Sub-District had 5,107 hectares of rice harvested area with the productivity of 5.99 ton/hectares. Therefore, it is important to update information about rice planting areas in order to estimate its productivity accurately and to maintain Indonesian especially Cariu Sub-District food needs. This study aims to estimate the rice productivity in Cariu Sub-District, Bogor in 2017 using Sentinel-2 imagery based on remote sensing. In this study, NDVI (Normalized Difference Vegetation Index) method used for determines the rice growth phase. The result shows that the Sentinel-2 image utilization with NDVI algorithm can estimate rice productivity in 2017 in Cariu Sub-District. It was expected that the rice productivity obtained is almost by the data from the Department of Agriculture and Forestry in the Cariu Sub-District.

Keywords: Rice productivity, remote sensing, Sentinel-2, NDVI

1. Introduction
Rice is the world’s most important staple food crop for more than three billion people (i.e., approximately 50 % of the World’s population) [1]. Most rice production has grown in Asia, where 60 % of the World’s population lives [2]. Although Indonesia as an agricultural country and the third largest rice producer in the World [3], its rice consumption is 98 kg per year, but the ability to produce it is only 75.40 million tons for food stock needs and supplying some areas that are deficient [4].

Cariu Sub-District is one of the leading rice producers in Bogor Regency, West Java, Indonesia. In 2017, Cariu Sub-District had 5,107 hectares of rice harvested area with the productivity of 5.99 ton/hectares [5]. Cariu District has not been able to self-sufficient food [6]. Therefore, it is important to update information about rice planting areas in order to estimate its productivity accurately and to maintain Indonesia; especially Cariu Sub-District food needs [7].

In this era of globalization, remote sensing technology has quickly evolved and extensively implemented to observe and map rice crop [8]. Remote sensing is the discipline of accessing data about an object or area applied electromagnetic radiation (light) without direct contact with the object or area of study [9]. Compared to conventional one’s ground-based monitoring, remote sensing techniques are far more effective and economical to monitor and map on a regional scale, especially in
areas that are difficult to reach [10]. Remote sensing technology be able to give temporal and detailed data about planted crop distribution area, potential production, and productivity [11].

A lot of analysts apply multi-temporal optical images (e.g., Landsat, MODIS, AVHRR, and SPOT-VGT) to generate rice maps through following methods and parameters such as: Spectral Matching Techniques (SMT), Decision Tree algorithm (DT), Maximum Likelihood algorithm (ML) and Support Vector Machine (SVM) with commonly using remote sensing-based vegetation index [i.e., Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Land Surface Water Index (LSWI) [12-16]. Moreover, there is Sentinel-2, with a 10-days repeat cycle, which is a multispectral and radar satellite launched on June 23, 2015 by European Space Agency (ESA) in Guiana Space Centre, Kourou, French Guyana [17]. Therefore, the study used the Normalized Difference Vegetation Index (NDVI) with multi-temporal Sentinel 2A data for rice productivity estimation. The other aim of this study was to compare the rice productivity estimation with the data from the Department of Agriculture and Forestry in Cariu Sub-District, Bogor, West Java in 2017.

2. Methodology

2.1. Study area and data sets

The field in this study (107°4’42” – 107°11’33” E, 6°27’56” – 6°34’40” S) located in Cariu Sub-District, Bogor, West Java. The topography of the study area characterized by the form of a plain with an estimated area of ± 72 %, and another part is ± 28 % in the form of mountains, hills, and rivers. The elevation of the study area is in the range of 37–469 m above sea level (MASL), and slopes range of 0–10 %. Climatically, the study area has an average daily temperature of 20–30 °C and annual precipitation of 2500 mm.

The Sentinel-2A imagery that used is at the recording of March 6th, April 15th, and May 5th, 2017. Field surveys conducted on October 15th, 2018 to obtain productivity of 30 sample points for NDVI values identification and land use validation. Unfortunately, there is no farmer in the rice field of sample point when field surveys conducted, so the productivity of sample point refers to the author’s other field studies in Subang. Another production and productivity data of rice from the Department of Agriculture and Forestry in the Cariu Sub-District will compare.

2.2. Image processing

Sentinel-2 Level 1C imagery had been corrected geometrically and radio-metrically in reflectance values of ToA [18]. Satellite imagery is crop according to the study area to proceed with NDVI algorithm in ENVI 5.1 software. The NDVI formula as follows:

\[
NDVI = \frac{NIR - \text{Red}}{NIR + \text{Red}}
\]

where, \text{Red} and \text{NIR} are the reflectances in RED and NIR, respectively. Then the image is overlaid with a land use map using ArcGIS 10.1 software, which only shows rice fields land use. The result is the Sentinel-2 image with NDVI algorithm in the study area with rice fields land use.

2.3. Rice phenology identification

The NDVI values are in the range from -1 to +1, as high as NDVI values, as close as the rice plant to starts harvest phase. Index values vegetation are getting closer to +1 (0.8–0.9) shows high vegetation density. NDVI values during the rice growth phase until the harvest period forms a curve. The highest NDVI value located at the top of the curve, which is when the rice is in the optimal vegetative phase (about 8–13 weeks after planting). Otherwise, the decreasing NDVI values show that the plant is not in
productive phases [18]. Based on these, the NDVI values classification in table 1 could be used to
determine the estimated harvest from rice plants.

2.4. Correlation between NDVI and rice productivity
The estimation of rice production is built based on the close correlation between NDVI values and productivity. NDVI values used when rice is ready to harvest (reaches 80–90 days or 8–13 weeks after planting) [18]. The correlation between NDVI values and rice productivity in Subang in $R^2$ is 0.68, means the correlation is high [19]. Based on this, the research in Subang would use as references in the study area. Also, there are some similarities related to the management of rice fields in Subang and the study area. The NDVI values of study area divided by the NDVI values in Subang is equal to the rice productivity of study are divided the rice productivity in Subang.

\[
\frac{\text{NDVI values of study area}}{\text{NDVI values in Subang}} = \frac{\text{Rice productivity of study area}}{\text{Rice productivity in Subang}}
\]

(2)

3. Results and discussion

3.1. Vegetation index algorithm
Rice field distribution dominated at the north of Cariu Sub-District. Rice productivity can be estimated from one month before the rice harvested [18]. The rice planting periods of the study area are on November–January, and April–June. Unfortunately, the satellite image quality in January and February 2017 are lousy quality. So, this study only used March–May 5th, 2017 of satellite image to see NDVI values of second rice planting periods. The NDVI values from March to May keep increase, indicating the high vegetation density (figure 1). The NDVI values obtained depend on the quality of images that is cloud free.

3.2. Rice phenology
Rice phenology distribution in Cariu Sub-District on the first-period rice planting is equally spread. As shown in figure 2, the rice phenology at the north of study area on March is dominated by 3–4 weeks after rice planting and some 4–6 weeks after planting at the south-west. Then, in April is dominated with 4–8 weeks after rice planting. The optimum vegetative phase with 8–13 weeks after planting is on May 2017. Based on these, the rice will be harvested in June 2017. However, operational crop monitoring and yield prediction based on optical remote sensing are hindered by unfavorable atmospheric conditions, which can lead to data gaps especially during critical growth stages [20].

3.3. Correlation between NDVI and rice productivity
Rice productivity of study area obtained after calculates the equation 2. The correlation between NDVI values and rice productivity in Cariu Sub-District in $R^2$ is 1 as shown in figure 3, means

| Table 1. NDVI values classification for rice phenology identification [18]. |
|-----------------|-----------------|-----------------|
| NDVI values     | Vegetation density | Age of rice plant |
|                 | (weeks after planting) |                 |
| -0.0.96–0.036   | No vegetation/ open space/ water | < 3 |
| 0.036–0.240     | Very low          | 3 – < 4         |
| 0.240–0.456     | Low              | 4–6             |
| 0.456–0.652     | Moderate          | 6–8             |
| 0.652–0.884     | High             | 8–13            |

After optimum vegetative of NDVI values, it will drop according to the maturity of the grain.
Figure 1. NDVI Values of rice field in Cariu sub-district, Bogor.

Figure 2. Rice phenology (weeks after planting) in Cariu sub-district, Bogor.
the correlation is very high [19]. The high correlation of NDVI values and rice productivity due to rice productivity of study area obtained from the ratio of NDVI values and rice productivity of author’s other field study in Subang.

3.4. Comparison of Rice Productivity estimation and secondary data

Table 2 shows the rice productivity estimation compares with data from the Department of Agriculture and Forestry in the Cariu sub-district. The minimum of rice productivity estimation is 6.08 tons in Karyamekar, the maximum is 6.25 tons in Tegalpanjang, and the average is 6.16 tons. The minimum of rice productivity from Department of Agriculture and Forestry is 6.11 tons in Sukajadi and Karyamekar. Root Mean Square Error (RMSE) is the standard deviation of residuals (prediction errors). RMSE of both rice productivity data is 0.04 means low error data level so that rice productivity estimation could be used in the future.

![Figure 3. Correlation of NDVI and rice productivity in Cariu sub-district, Bogor.](image)

Table 2. Comparison of rice productivity estimation and secondary data.

| Villages       | Rice productivity estimation (ton/ha) | Rice productivity* (ton/ha) |
|---------------|--------------------------------------|-----------------------------|
| Tegalpanjang  | 6.25                                 | 6.22                        |
| Cariu         | 6.10                                 | 6.21                        |
| Babakan Raden | 6.14                                 | 6.15                        |
| Sukajadi      | 6.10                                 | 6.11                        |
| Kutamekar     | 6.15                                 | 6.15                        |
| Cikutamahi    | 6.23                                 | 6.21                        |
| Bantarkuning  | 6.22                                 | 6.22                        |
| Cibatutiga    | 6.17                                 | 6.17                        |
| Karyamekar    | 6.08                                 | 6.11                        |
| Mekarwangi    | 6.21                                 | 6.21                        |
| Average       | 6.16                                 | 6.17                        |
| RMSE          | 0.04                                 |                             |

*from the Department of Agriculture and Forestry
Figure 4. Estimation of rice productivity in Cariu sub-district, Bogor, West Java 2017.

Figure 4 shows the distribution of rice productivity estimation in Cariu. The lowest rice productivity of the study area is at south-west in Karya Mekar. Rice productivity between 6.10–6.20 tons is at the north to south of study area. The highest rice productivity of the study area is at north-west and south-east, above 6.20 tons. Different values of rice productivity in each village due to differences in physical factors and rice field management factors. Physical factors that affect rice productivity are elevation, slope, soil type, and climate. The difference in paddy management is the irrigation system, the type of fertilizer, the amount of fertilizer, and the intensity of fertilizer given.

4. Conclusion
The conclusion of the research, first the Sentinel-2 data image processing with NDVI algorithm can estimate the rice phenology, and it could be used as a base to estimate time harvest and harvested area. Second, the NDVI values have a positive correlation with rice productivity and the increased of NDVI values followed by the increase in rice productivity. Third, the standard deviation of rice productivity estimation and data from the Department of Agriculture and Forestry is 0.01 and RMSE of 0.04. Moreover, fourth, the cause of the deviation is the rice productivity data from the Department of Agriculture and Forestry is already average rice productivity of Cariu Sub-District. The other hand, rice productivity estimation based on NDVI values from image processing shows that each village has varied NDVI values. Thus the rice productivity obtained also varies according to the NDVI value.

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References

[1] Khush G S 2005 *Plant Mol. Biol.* **59** 1-6
[2] Rosegrant M W and Cline S A 2003 *Science* **302** 1917-9
[3] Mosleh M K, Hassan Q K and Chowdhury E H 2015 *Sensors* **15** 769-91
[4] Badan Pusat Statistik 2015 *Produksi Padi Tahun 2015 Naik 6,42 Persen* available at https://www.bps.go.id/pressrelease/2016/07/01/1272/produksi-padi-tahun-2015-naik-6-42-persen.html
[5] Badan Pusat Statistik Kab. Bogor 2017 *Kecamatan Cariu dalam Angka 2017* available at https://bogorkab.bps.go.id/publication/2017/12/22/86f3be650d3479daa6b9f8aa/kecamatan-cariu-dalam-angka-2017.html
[6] Kurniasari N, Pangi and Harahap A A 2017 *Prosiding Seminar Nasional Geomatika* 2017 (Indonesia: Badan Informasi Geospasial) pp 165-74
[7] Wang J, Xiao X, Qin Y, Dong J, Zhang G, Kou W, Jin C, Zhou Y and Zhang Y 2015 *Sci. Rep.* **5** 10088
[8] Yang H, Pan B, Wu W and Tai J 2018 *Int. J. Appl. Earth Obs. Geoinf.* **69** 226-36
[9] de Jong S M and van der Meer F D 2004 *Remote Sensing Image Analysis: Including the Spatial Domain* (Dordrecht: Kluwer Academic, Netherlands)
[10] Corcione V, Nunziata F, Mascolo L and Migliaccio M 2016 *Int. J. Remote Sens.* **37** 633-47
[11] Shao Y, Fan X, Liu H, Xiao J, Ross S, Brisco B, Brown R and Staples G 2001 *Remote Sens. Environ.* **76** 310-25
[12] Gumma M K, Nelson A, Thenkabail P S and Singh A N 2011 *J. Appl. Remote Sens.* **5** 053547
[13] Gumma M K, Thenkabail P S, Maunahan A, Islam S and Nelson A 2014 *ISPRS J. Photogramm. Remote Sens.* **91** 98-113
[14] Nuarsa I W, Nishio F, Hongo C and Mahardika I G 2012 *Int. J. Remote Sens.* **33** 5402-17
[15] Peng D, Huete A R, Huang J, Wang F and Sun H 2011 *Int. J. Appl. Earth Obs. Geoinf.* **13** 13-23
[16] Xiao X, Boles S, Liu J, Zhuang D, Froliking S, Li C, Salas W and Moore B 2005 *Remote Sens. Environ.* **95** 480-92.
[17] ESA2015 available at https://sentinel.esa.int/web/sentinel/home
[18] Pradipta D 2012 *Analisis Data Time Series NDVI-SPOT Vegetation untuk Tanaman Padi (Studi Kasus: Kabupaten Karawang)* BSc Projects (Bogor: Bogor Agriculture University)
[19] Guilford J P and Fruxhter B 1977 *Fundamental Statistics in Psychology and Education*, 6th edition (New York: McGraw Hill)
[20] Koppe W, Gnypa M L, Hütt C, Yao Y, Miaoc Y, Chen X and Bareth G 2013 *Int. J. Appl. Earth Obs. Geoinf.* **21** 568-76