SPATIO-TEMPORAL PATTERN OF PADDY RICE PLANTING ESTIMATED BY USING MODIS DATA PRODUCT AND ITS CORRELATION WITH RAINFALL VARIATIONS - A CASE STUDY OF JAVA, INDONESIA -

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Abstract: The author developed a method to estimate time of planting paddy rice using 16-day composite vegetation indices MODIS product (MOD13Q1) and applied it to Java Island in Indonesia. The model employed EVI of the product and NDWI (Normalized Difference Water Index), which represented surface water condition, calculated from Band 1 and Band 7 stored in the product. Rice planting time was estimated from time-series EVI and NDWI and assessed by comparison with statistics data. Java Island located in the tropical monsoon climate region is representative rice production area and its cropping season normally started at the beginning of rainy season around October. We estimated the time of first and second rice planting time starting from September for the year from 2000/2001 to 2010/2011 and could demonstrate averaged time of rice planting with spatial distribution pattern and also variations of time year by year for whole Java Island. Standard deviation of length of planting time for the first period were as long as 2 months at widely distributed areas and its range showed longer term compared with the second period. In order to analyze the relation between time of planting rice and condition of rainfall, we first judged the tendency of much or less of rainfall amount to the normal at each year by using rainfall record for 10 stations located in the study site. As a result of calculation of correlation, we could identify areas where time of rice planting tended to be delayed in case of less rainfall in the first half of rainy season and also areas where time tended to be delayed in case of much rainfall. This information would be expected to apply to management of water resources and enhancement of stability of rice production at the site.

INTRODUCTION

Rice is cultivated widely in Asian Region from tropical to cold-temperate climate zones in harmonized with physical conditions of location. In the most tropical climate zone, temperature could be suitable for cultivating rice all the year, however, availability of water on planting time would be a critical factor for executing transplanting of paddy rice. Therefore, some areas, where function of supplying water was not established, would exhibit considerable variation of time of planting rice year by year. Although such a variation of planting time of rice was significant feature for understanding trend of rice production at the target area, it could not be grasped in detail from conventional statistics information. From this background, it is necessary to establish a scheme of monitoring of spatio-temporal characteristics of rice planting. Also, it is meaningful to identify areas where time of planting rice prone to be varied. Thus, satellite remote sensing has been believed as promising tool for these purposes.

In order to grasp planting time of rice through the year, high temporal resolution data would be a potential source for analysis. Then, a number of research examined applicability of MODIS data to characterize the pattern of rice planting for wide area in Asian region (e.g. Takeuchi and Yasuoka, 2004; Sakamoto et al, 2006; Xiao et al, 2006). These studies could show spatial distribution of rice planted area and also representative pattern of cropping properly in various areas but could not show optimally for the case of comprising complex patterns of cropping as extensively appeared in Indonesia. Then the author examined applicability of MODIS composite data to estimate rice planted time for the case of West Java in Indonesia (Uchida, 2007) and he modified it to be adopted by 16-day composite MODIS data product (Uchida, 2010ab).

These studies exhibited that time of planting rice could be successfully identified and features of variation were properly characterized for the site where large scaled irrigation system was constructed. Results also suggested a relation between patterns of rainfall in early rainy season and variation of rice planted time. One paper concluded that there was a strong correlation between 90-day cumulative precipitation and cultivated paddy field acreage, which was estimated from Landsat data, in case of western part of Java Island (Yoshikawa and Shiozawa, 2006). But this study could not examine variation of spatial pattern in detail and also it limited to the case of limited years. Therefore, further studies would be required on relation between pattern of rice planting time, which was obtained from high temporal resolution satellite data, and environmental factors such as rainfall.

MODIS is a representative high temporal resolution satellite data adopted to study on changes of land surface in global to regional scale and numbers of dataset processed for specific objectives by using MODIS data are supplied to users. Then, objective of this study is first to verify applicability of MODIS data product for characterizing and demonstrating patterns of variation of planting time of rice in recent years for case study site of Java Island of Indonesia, where times of cropping are complicatedly mixed. The second objective is to discover relationship between time of planting rice and variation of rainfall.

STUDY SITE

The study site is Java Island and adjoining Madura Island of East Java Province, of which total acreage is 127 thousand square kilometers and population was 136.61 million in 2010. This is the most intensive rice producing area in Indonesia and annual production of rice in this area was 33.47 million tons from 5.91 million hectares of harvested area according to statistics data by Central Statistics Bureau of Indonesia (http://www.bps.go.id/). Geographically, the site is located between 105 and 115 degrees of east longitude and between 6 and 9 degrees of south latitude as shown in Figure 1. Topographically, alluvial plains are presented along parts of coastal area and a number of mountains, of which peak elevation are more or less 3,000 meters, exist along middle part of the island. Annual rainfall has wide spatial variation, i.e. from less than 1,000 to more than 4,000 millimeters, and generally it shows higher amount around mountains. Temperature is high enough to grow rice through the year except for part of high altitude, say more than 1,500 meters, so that rice could be cultivated at any season if water was supplied sufficiently. Cropping time of paddy rice per year exceeds twice in extensive area, for example, averaged time in West Java Province was 2.45 in 2005 according to agricultural statistics information.

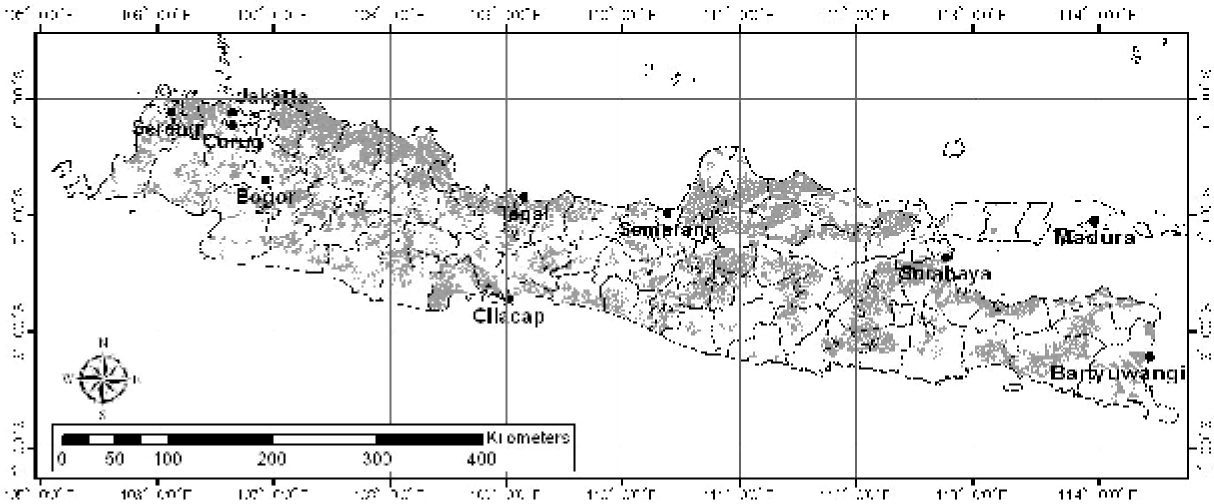

Figure 1: Map of study site (Gray tone: paddy field, Dot: rainfall station)

DATA & METHODS

In this case study, I aimed at analysis of variation of paddy rice planted time of the site, where rice planted time might be changed year by year, using MODIS data. MODIS data employed here was Vegetation Indices 16-day Global 250 m product (MOD13Q1), and data in tiles assigned h28v9 and h29v9 for the period from February 2000 to March 2011 downloaded from the site ftp://e4ftl01.cr.usgs.gov/MODIS_Composite/MOLT/MOD13Q1.005/. MOD13Q1 contains EVI (Enhanced Vegetation Index), NDVI (Normalized Difference Vegetation Index) and reflectance values of Band 1, 2, 3 and 7 of MODIS data. Then in this study, additional index, NDWI (Normalized Difference Water Index), which represented surface condition whether covered by water or not, was calculated by following equation.

$$NDWI = \frac{B1 - B7}{B1 + B7},$$

where Bi is reflectance value of band i of MODIS data.

There is similar data product namely MYD13Q1 processed from Aqua/MODIS data, while MOD13Q1 was processed from Terra/MODIS data. In this study, only MOD13Q1 was used for analysis because its continuity of length of observation was longer than the other one. Also by preliminary examination, it was recognized that 8-day composite product could not remove optimally the deterioration of quality of data due to cloud especially in rainy season. By this reason 8-day composite data was not employed in this study.

Statistics data about monthly acreage of planted paddy rice by Sub-District for Cianjur District of West Java Province was collected at District Agricultural Office. This contained time series data from the year from 2001 to 2008. Paddy field distribution data was obtained from National Mapping Agency of Indonesia. This data was produced by means of manual interpretation of LANDSAT-ETM+ imagery and Figure 1 shows paddy field distribution expressed by using gray tone. Rainfall data was obtained for 10 stations, of which locations are also indicated in Figure 1, from dataset compiled by NCDC (National Climatic Data Center) of NOAA.

In the previous studies (Uchida, 2010ab), I indicated for the case study of West Java that the maximum of NDWI was appeared at time of transplanting paddy rice and EVI was sharply increased after the time of transplanting. Then I analyzed relation between paddy rice planted time which was obtained from statistical information and temporal changes of NDWI and EVI. As a result, I constructed a scheme of estimating time of planting rice as shown in Figure 2.

Estimation of rice planted time was verified by comparison with statistics data. I selected statistics data of Ciranjang Sub-District of Cianjur District, because rice was planted twice per year and each planting period was concentrated in around one month for this Sub-District. For other areas, rice planting period was to be diversified and it was difficult to employ statistics data for the purpose of comparison. Figure 3 shows relation between values of ratio of rice planted area to area of paddy field according to statistics in horizontal axis and values of ratio of rice planted area estimated by using MODIS data to area of paddy field calculated from map data in vertical axis. This figure shows good correlation between two components so that estimated time was supposed to be generally matched with actual planted time. It also should be noticed that estimated area was smaller to actual acreage. This implies that not all the rice planted area could be discriminated its planting time properly and thus accurate estimation of acreage of rice planted area would not be possible by the method introduced here. The method explained above might be applicable to other areas where land use condition was similar, therefore in this study, the same procedure was adopted to estimate rice planted time for whole Java Island.

Rainfall data was daily based information, but missing of record was found in considerable number of date in a year for every stations. Therefore, firstly I examined correlation of yearly changes of seasonal rainfall among stations and then identified tendency of more or less to the normal about accumulated rainfall for former part of rainy season. This tendency of rainfall was adopted for analysis of relation between rice planted time and rainfall.

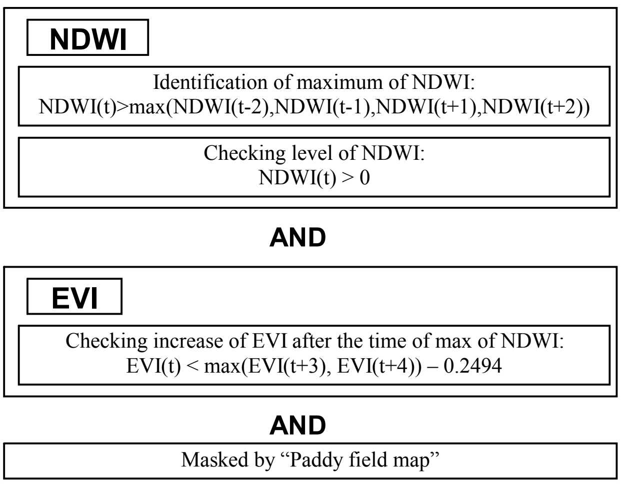

Figure 2: Scheme of estimating time of planting paddy rice using MODIS data

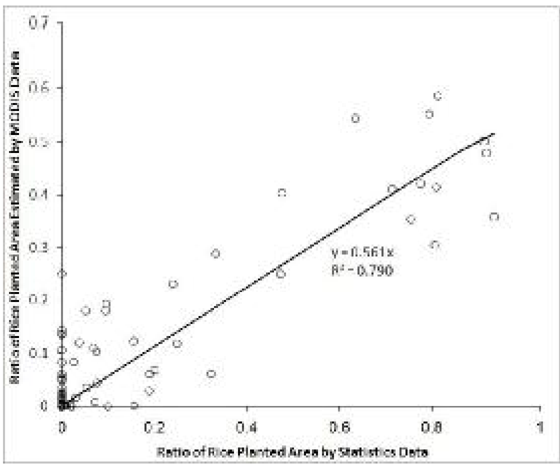

Figure 3: Relation ratio of rice planted area to paddy field between by statistics and estimation by MODIS data

RESULTS & DISCUSSIONS

Figure 4 depicts distribution of first rice planted time averaged for the period from 2000/2001 to 2010/11. At this, first rice planted time was defined as the first occurrence since September, because rainy season as well as cropping calendar generally started from October. This figure shows spatial transition pattern of rice planted area associated with progress of time as that from inland to northward in the northwestern coastal area, where large scale irrigation system was constructed. Another area equipped with large scale irrigation system was located in northern central coastal part and it showed earlier rice planted time. In inland part, of which water was supplied by more or less local scaled irrigation system, rice planted time tended to be heterogeneously distributed.

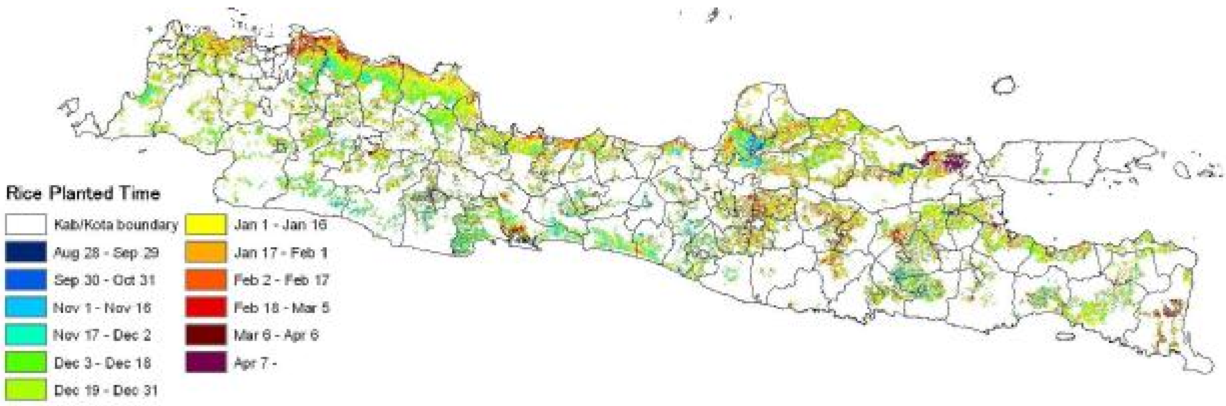

Figure 4: Distribution of first rice planted time estimated by using MODIS data

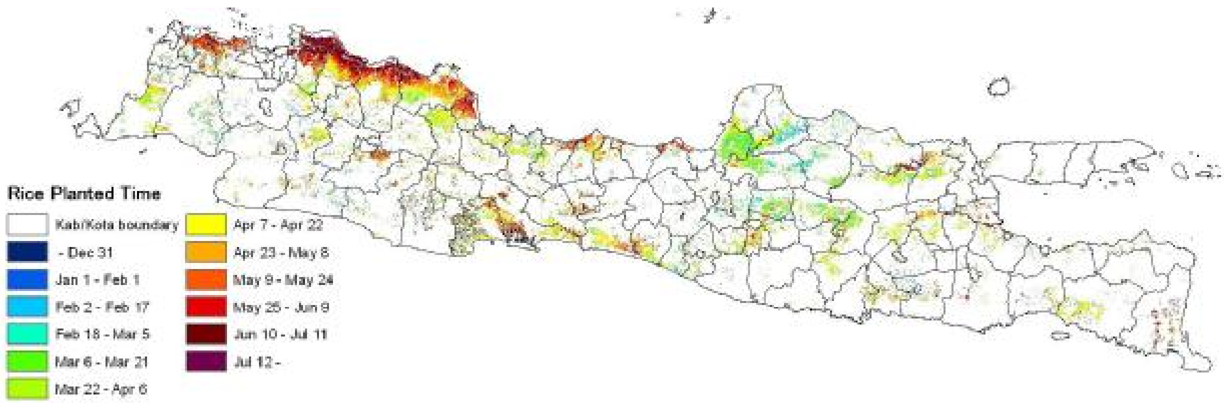

Figure 5: Distribution of second rice planted time estimated by using MODIS data

Figure 6: Distribution of time difference between first and second rice planted time

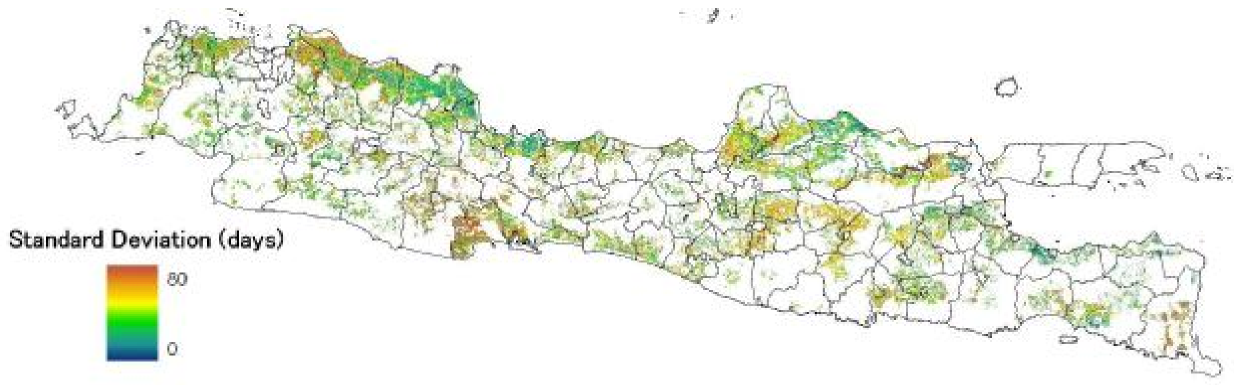

Figure 7: Distribution of standard deviation of first rice planted time estimated by using MODIS data

Figure 5 represents distribution of second rice planted time averaged for the same period. From this figure, it is recognized as a feature of relatively late planting in the northwestern coastal area compared to other parts. Then, as shown in Figure 6, time difference between first and second rice planted time in this area tends to be longer. Considering about remaining length of period to next first rice planting, this area should be dominantly implemented by double cropping of rice. Contrastively, time difference appeared in inland area tends to be shorter and this suggests that triple cropping of rice could be implemented in condition of supplying sufficient amount of water.

Figure 7 shows distribution of standard deviation of first rice planted time for the same period as Figure 4. Averaged standard deviation value for the whole site was calculated as 45 days and the higher value was presented around marginal part of large scale irrigation system or inland area. This figure indicates that time of planting rice could be varied in a range of more than one month for most of paddy field in the site.

Figure 8 shows yearly trend of deviation of date of rice planted time from averaged value. In this figure, positive value of vertical axis denotes that planted time was later to the average and negative value denotes earlier to the average. Here, averaged date of first rice planted time over the whole site was January 5th and second planted time was May 1st. It is recognized from the figure that planted time was varied distinctively year by year and deviation tendency of both planted time was synchronized with having generally biennial pattern.

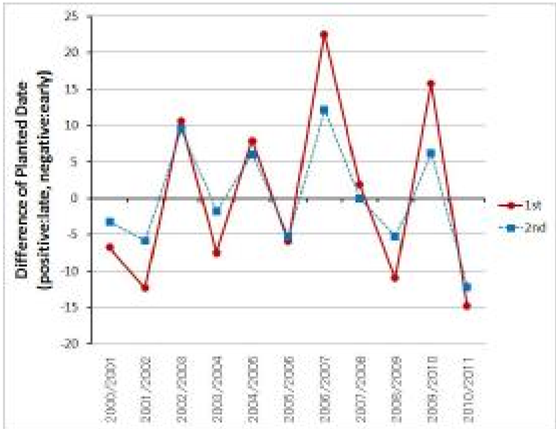

Figure 8: Yearly trend of deviation of date of rice planted time from averaged value

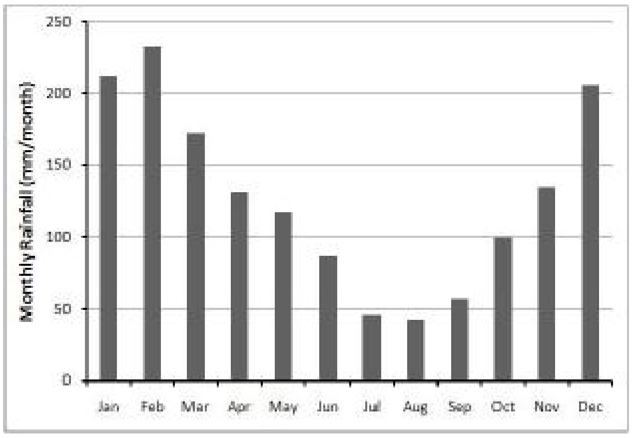

Figure 9: Monthly rainfall averaged over 10 stations in Java

One probable factor to make shift of date of rice planted time was pattern of rainfall. Figure 9 shows monthly rainfall averaged over 10 stations, of which monthly values are mean for the period from 2005 to 2010. Because of number of missing daily record, this value could be lower than actual one. In order to recognize spatial relation of pattern of rainfall, correlation coefficients of yearly variation of rainfall among stations were calculated for divided terms as follows, January to April, May to August, September to December, which were corresponding to latter rainy season, dry season, former rainy season, respectively, and annual total. Then it was revealed that there was high positive correlation among all stations for yearly variation of rainfall, except for the term from January to

April. By this result, it could be characterized that rainfall in former part of rainy season, i.e. September to December, would show similar tendency, which meant more or less to the normal, for whole part of study site.

I analyzed rainfall data at 10 observation points and additionally employed monthly rainfall data at 3 stations in West Java Province for characterizing yearly tendency through the all period from 2000 to 2010. Then, it is resulted that 2000, 2001, 2002, 2004, 2006 and 2009 were less than normal amount of rainfall for the period from September to December and rest of years were more than normal. By using this feature of rainfall, correlation between planted time of rice and rainfall amount was examined by the following method. If rice planted time for specific year was earlier than average, parameter set as -1 and if it was earlier more than 32 days, set as -2. Conversely, if rice planted time was later than average, it set as +1 and +2 for the case of later more than 32 days. Multiplication of this parameter by factor on rainfall pattern of each year, i.e. +1 for more amount of rain and -1 for less amount of rain, was summed for all the year.

Figure 10 represents the correlation between first rice planted time and rainfall followed by the method mentioned above. Bluish color in this figure indicates a part of rice planted time tended to be delayed in case of more amount of rainfall and reddish color indicates a part of rice planted time tended to be delayed in case of less amount of rainfall. In the figure, reddish parts are generally presented at lower part of large scale irrigation network and at foot of mountains. This figure could suggest that bluish part was flood prone area where rice planting would be delayed by high water level after large amount of rainfall and that reddish part was drought prone area where rice planting would be delayed by insufficiency of water.

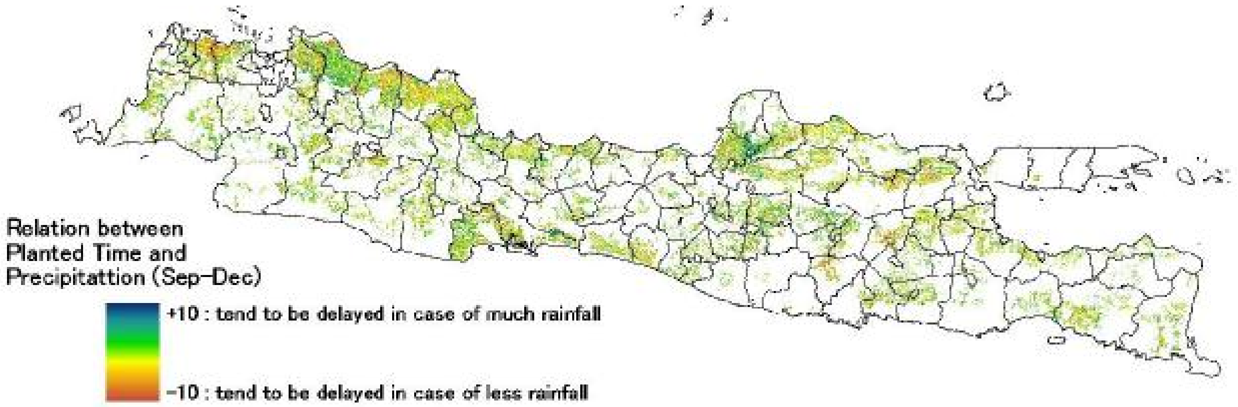

Figure 10: Correlation between first rice planted time and rainfall

CONCLUSIONS

This study utilized one of MODIS data product, which was distributed to the public, and successfully adopted it to provide both temporally and spatially seamless data of planting time of paddy rice for whole Java Island in Indonesia. Although the method developed in this study was not sophisticated scheme and remained limitation of estimation of acreage of rice planted area, it was still effective to discover areal characteristics of rice planted time year by year and to analyze relation between rice planted time and variation of rainfall. The results of Java case study demonstrated geographically and visually location of areas, where time of planting rice was changeable due to excess or scarcity of water. This provided spatially detail information on location of flood prone or drought prone area and it would contribute to construct more optimal agricultural land use/cropping system as well as management of water resources than present condition in regional scale.

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