MONITORING OF PLANTING PADDY RICE WITH COMPLEX CROPPING PATTERN IN THE TROPICAL HUMID CLIMATE REGION USING LANDSAT AND MODIS DATA - A CASE OF WEST JAVA, INDONESIA -

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ABSTRACT:

This study aimed at the development of method of monitoring paddy rice planting applicable to areas located in the tropical humid climate region. The method was integrated with two steps of procedure. As the first step, we attempted to produce land use map which discriminated paddy field using multi-temporal Landsat data. In order to remove the effect of cloud cover, a new method of land use classification was introduced. This method employed five indices, which could represent the specific condition of ground surface on soil, vegetation or water, derived from Landsat data, and discriminated land use by using maximum values of indices for multi-temporal scenes. The results showed meaningful improvement in accuracy of discrimination compared to conventional method of land use classification using spectral information of Landsat data. Paddy field extracted by this step was used as paddy mask data in the following step. The second step was to construct a method to judge the time of rice planting using MODIS data. In this study, we examined the time series of EVI (Enhance Vegetation Index) and NDWI (Normalized Difference Water Index) obtained from 16-day composite MODIS vegetation product dataset in combination with statistical information obtained from local administrative offices. We developed a scheme that could estimate the place of paddy rice planting after about two months from planting. The results showed a capability of identifying time of planting rice for extensive part of West Java using MODIS data and contributed to analyze the pattern of spatial transition of area of planting for recent years.

1. INTRODUCTION

1.1 Background

Satellite remote sensing is a powerful tool to monitor the changes of land surface conditions from its capability of periodical observation over the same site. Seasonal changes of land surface are associated with land use type, especially agricultural land use, therefore, monitoring of cultivation of specific crop was a target of application of remote sensing. Rice is the most significant staple food crop cultivated widely in the tropical to temperate climate region, and a number of researches had been carried out to estimate state of rice planting using remote sensing data.

Mapping of paddy field was a target by using Landsat data. Attempts were partially successful for the site located in the temperate climate zone, where rice was planted in the limited period of the year. For the site located in the tropical humid climate region, however, method of paddy field extraction was not successfully developed due to the high probability of cloud cover and also wide variation of existing cropping patterns. In case of Indonesia, of which the study site was included, several national institutions produced land use map discriminating paddy field, from Landsat data by means of manual interpretation of the imagery. These maps depicted general spatial distribution of paddy field but contained problems of inconsistency of interpreted areas between different institutions as well as spatially low accuracy compared with pixel based classification. Therefore, it is required rationally obtained paddy distribution data with spatial resolution compatible to the size of agricultural fields. The author attempted to develop a method to produce paddy distribution map applicable to the study site and showed promising result by preliminary examination (Uchida, 2008).

Cropping pattern of rice could be monitored by analyzing phonological features obtained from high-temporal resolution satellite data. MODIS was employed as the source data to characterize the pattern of rice planting in Asian region (Takeuchi and Yasuoka, 2004; Sakamoto *et al*, 2006; Xiao *et al*, 2006). These studies showed successfully the pattern of spatial distribution of rice planted area in the continental scale, and also presented properly temporal changes of rice cultivated area in the large scale irrigated land. However, the results of these studies could not be optimized to estimate the case of complex cropping pattern typically presented in West Java, Indonesia. At this point it is significant to implement further study of method of monitoring rice planting, which should be applicable to the tropical humid region. Then, the author preliminarily examined adaptability of composite MODIS data for estimating rice planting time in Indonesian case study (Uchida, 2007).

1.2 Objectives

The methods developed by the author mentioned above could be noticed as useful tools for monitoring paddy rice planting, but he has not yet assessed their adaptability or accuracy. Therefore, the first objective of this study is to assess both of developed methods for their adaptability for the case of tropical humid climate region and to evaluate reliability of estimation.

The second objective is to characterize spatio-temporal features of rice planting by using produced time series data of rice planting for the study site.

1.3 Study Site

The study site is located in the western part of Java Island of Indonesia involving West Java, Banten Provinces and Jakarta Metropolitan, as shown in Figure 1. Topographically, alluvial plain extends along the northern coastal side and mountains, of which the elevation exceeds 2,000 meters, are situated in the middle part of island. Annual rainfall varies widely from around 1,200 mm in the northern coastal area to more than 4,000 mm in the mountainous area. Dry season is presented normally from May to September, but it is not distinctive especially in the mountainous area.

West Java is the most intensive rice production area, where average of rice planting on paddy field was 2.45 times per year in 2005. In the part of alluvial plain of the northern part, paddy fields are extended widely in association with large scale irrigation networks. Cropping calendar of this area is generally started from October in harmonized with the onset of rainy season. In the part of foot of mountains, on the other hand, cropping season tends to be randomized under the condition of unsystematically arranged irrigation systems.

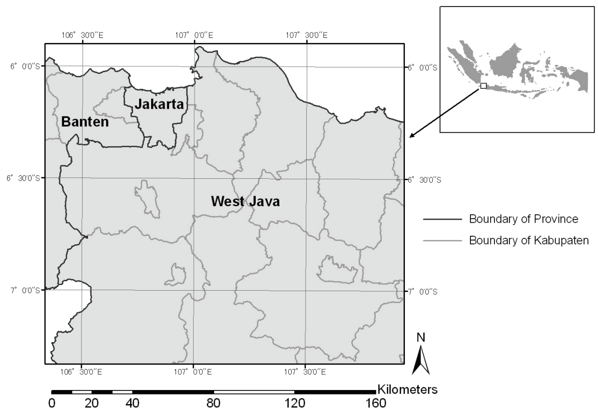

Figure 1. Location of study site

2. METHODS

2.1 Discrimination of Land Use

Discrimination of land use employed in this study was based on the temporal change of land cover features. For example, paddy field was inundated by water during the time of transplantation, and it was covered by vegetation when rice was grown up, then covered by bare soil after the harvest and preparation period. On the other hand, conditions of surface coverage of upland field were either vegetation or bare soil through the year. Therefore, even if the sampling time was discretely distributed and its interval was irregular, maximum value of indices, which reflected the surface condition of water, vegetation or soil, for all the sampled data was to be discriminating factor of land use types. The author employed 3 indices calculated from Landsat TM and ETM+ data and examined the capability of land use discrimination (Uchida, 2008). In this study, 2 indices were added and totally 5 indices as described bellow were employed.

$$NDBSI_L = \frac{(B7 - B1)}{(B7 + B1)} \quad (1)$$

$$NDSI_L = \frac{(B5 - B4)}{(B5 + B4)} \quad (2)$$

$$NDVI_L = \frac{(B4 - B3)}{(B4 + B3)} \quad (3)$$

$$LSWI_L = \frac{(B4 - B5)}{(B4 + B5)} \quad (4)$$

$$NDWI_L = \frac{(B3 - B5)}{(B3 + B5)} \quad (5)$$

where *Bi* is converted reflectance value of band *i* of Landsat data.

All the indices were calculated for 8 scenes of Path-121, Row-64 to 65 taken during 1999 to 2003 and 11 scenes of Path-122, Row-64 to 65 taken during 1994 to 2002 as shown in Table 1. Owing to the high probability of cloud cover, number of scene taken in rainy season was low especially for Path-122. The collected Landsat data still included a part of cloud cover on the scene, therefore in order to remove the effect of cloud, first each Landsat scene was classified by ISODATA method and identified the cloud affected area. By the next step, the value of all indices changed to -1 for the affected area. Consequently, calculated maximum value of 5 indices among all Landsat data represented the characteristics of variation of land cover condition at the pixel, which would be used for discriminating land use.

Table 1. List of collected Landsat data

Rath : 121, Row : 64-65	Path : 122, Row : 64-65
1999. 9. 5 (D)	1994. 9.22 (D)
2000. 3.15 (R)	1995. 6. 5 (D)
2000. 8.22 (D)	1996. 6. 7 (D)
2001. 6.22 (D)	1997. 6.26 (D)
2002. 3. 5 (R)	1997. 7.12 (D)
2002. 5.24 (D)	1997. 8.29 (D)
2002.10.15 (R)	1997. 9.14 (D)
2003. 1.19 (R)	1999. 8.27 (D)
	2001. 5.12 (D)
	2001.12.22 (R)
	2002. 8. 3 (D)

Note: (R) Rainy season, (D) Dry season

2.2 Estimation of Rice Planted Time

Time of planting rice was estimated by using Vegetation Indices16-day Global 250 m product (MOD13Q1) downloaded from site of ftp://e4ftl01u.ecs.nasa.gov/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. In this study, another index, NDWI (Normalized Difference Water Index), which could reflect the surface water condition, was calculated as the following equation from reflectance data.

$$NDWI = \frac{(B1 - B7)}{(B1 + B7)} \quad (6)$$

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

Preliminary examination indicated that appearance of maximum of NDWI at the time of transplanting rice and that a sharp increase of EVI and NDVI after the time of transplanting (Uchida, 2007). The author then performed the analysis of relation between planting time and changes of NDWI and EVI using statistical information on planting rice collected at the local agricultural offices. As a result, he constructed a model of estimating time of planting rice as shown in Figure 2. In this figure, "Paddy mask" data was obtained by adopting land use discrimination method explained in this article. Because the spatial resolution of discriminated land use data was not harmonized with that of MODIS dataset, land use data was treated procedures in the following; 1) to calculate ratio of existence of paddy field area in 9 by 9 adjoining pixels, 2) to convert to 250 meters resolution data, and 3) to extract of paddy area by threshold of more than 20 percents.

NDWI

Identification of maximum of NDWI:
NDWI(t)>max(NDWI(t-2),NDWI(t-1),NDWI(t+1),NDWI(t+2))

Checking level of NDWI:
NDWI(t) > 0

AND

EVI

Checking increase of EVI after the time of max of NDWI:
EVI(t) < max(EVI(t+3), EVI(t+4)) – 0.2494

AND

Masked by "Paddy mask" obtained from Landsat data

Figure 2. Model of estimating rice planting time applied to 16-day composite MODIS data

3. RESULTS AND DISCUSSIONS

3.1 Assessment of Land Use Discrimination

Figure 3 shows discriminated land use map for the study site. This data was obtained by ISODATA classification for 5 components indicated in Section 2.1. Number of class was set as 50 at the first and then grouped into 8 land use categories. This figure reveals that effect of cloud was totally removed from the image.

In order to assess accuracy of land use discrimination, the author performed comparison of land use type interpreted from QuickBird image. The QuickBird data employed in this study was taken on August 13, 2006, which observed central part of Bogor city and its vicinities. He interpreted manually type of land use at every 500 meters grid point and 714 points in total.

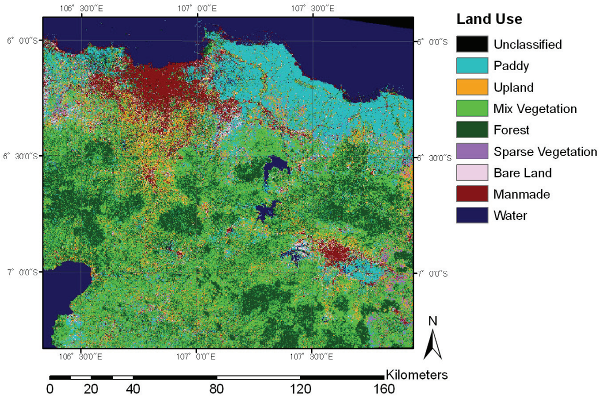

Figure 3. Land use map obtained by developed method

Table 2 shows confusion matrix of discriminated result to interpreted type from QuickBird. From this table, overall accuracy was calculated to 59.9 percents. If 2 set of classes are merged, i.e. "Upland" to "Mix Vegetation" and "Bare Land" to "Manmade", overall accuracy became 78.9 percents. This means the method developed in this study attained improvement of accuracy of discrimination for the site located in the tropical humid climate region, where land use system was complicated. Spatial size of land lot was often much smaller than the pixel size of Landsat in this area, therefore, land use discriminated from Landsat data was inevitably contained considerable amount of unclear class. However, it is noted that user's accuracy of discrimination of paddy field was sufficiently high, and this suggested that extracted paddy field could certainly be utilized as the source of "Paddy mask" data for the model of estimating rice planting time.

3.2 Evaluation of Estimation of Rice Planted Time

The author estimated rice planting time in the study site for the period since April 2000 to the December 2009. Figure 4 shows the estimated changes of rice planted area for the first 3 months in 2009 and the succeeding 3 months. This figure clearly

Table 2. Confusion matrix of discriminated result to interpretation class from QuickBird image

Estimated Land Use	Land Use interpreted from QuickBird Imagery								User's Accuracy (%)
	Paddy	Upland	Mix Veg	Forest	Sparse Veg.	Bare Land	Man-made	Water	
Paddy	29	1	0	0	2	1	0	0	**87.9**
Upland	11	98	74	0	9	7	3	0	**48.5**
Mix Vegetation	25	19	120	9	5	2	2	0	**65.9**
Forest	23	4	33	101	2	1	0	1	**61.2**
Sparse Vegetation	0	0	0	0	4	0	0	0	**100.0**
Bare Land	0	0	2	0	1	9	41	0	**17.0**
Manmade	1	0	4	0	1	1	65	0	**90.3**
Water	1	0	0	0	0	0	0	2	**66.7**

represented the spatial transition of rice planted area from inland side to coastal side and the repetition of this pattern in the northern coastal plain area, where large scale irrigation system was constructed. In inland area, on the other hand, there existed considerable scaled cluster of paddy planted area, but spatial transition of rice planted area could not be clearly represented. Moreover, in other part of the study site, it was rather difficult to characterize spatio-temportal feature of rice planting. This was presumably due to the situation that differently grown stages of rice were mixed in a pixel. However, the figure suggested that if cultivation of rice in terms of planting time was homogeneous with a certain extension, planting time of rice would be properly estimated and the spatio-temporal feature could be characterized.

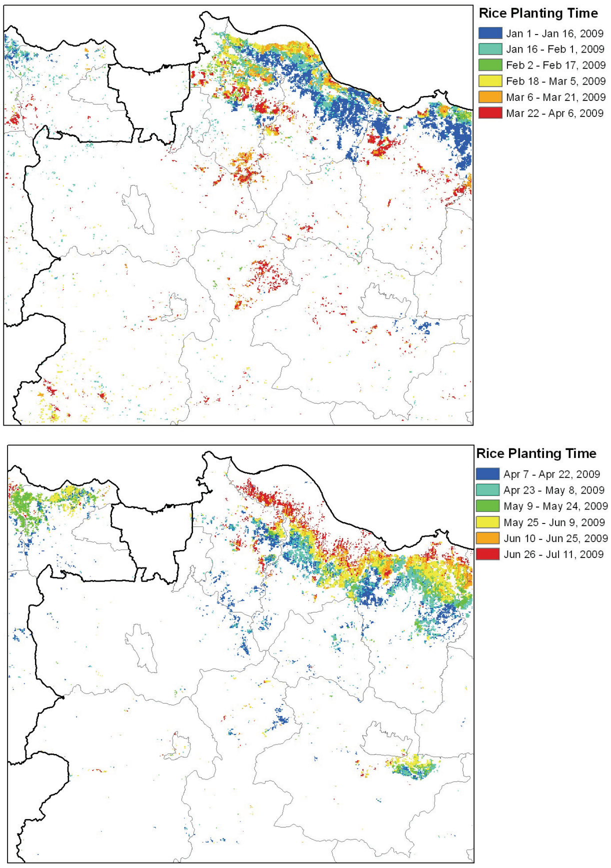

Figure 4. Estimated changes of rice planted area (upper: first 3 months in 2009, lower: succeeding 3 months)

In order to verify the estimated time of rice planting by the developed model, the author employed statistics data which indicated monthly planted area of paddy rice for each Sub-District (Kecamatan) compiled by the Agricultural Office of District (Kabupaten). Each Sub-District was featured to have variety of temporal patterns of rice planting by the analysis of statistics data, some were almost evenly distributed rice planted area for every month and the others showed distinctive peaks of rice planted area in a year. Ciranjang Sub-District of Cianjur District was representative area as the latter case, which exhibited two times of rice planting concentrated in almost one month respectively. Therefore, comparison was made by using the data of Ciranjang between estimated rice planted area by the developed model and statistics data.

Figure 5 shows time series of ratio of rice planted area to paddy field area. "Planted" denotes the ratio of rice planted area by statistics data and "Estimated" denotes the ratio of rice planted area calculated by using the model developed in this study. This figure depicts evidently the resonance of two time series data, only except for a few cases that the maximum of "Estimated" were earlier by about one month. Also, it is observed that the values of maximum of "Estimated" were lower to "Planted" at any case. This means that not all rice planted area was extracted by the developed method, presumably affected by the condition of mixture of differently scheduled rice planting.

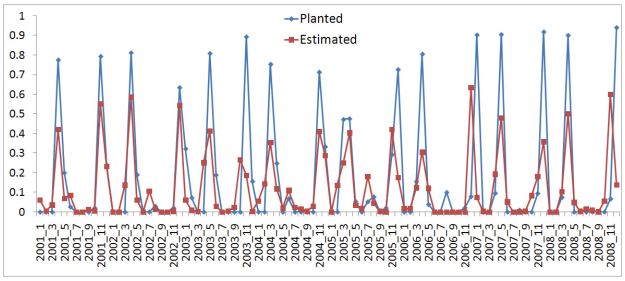

Figure 5. Time series of ratio of rice planted area to paddy field area in Ciranjang Sub-District for case obtained from statistics data (Planted) and estimated from MODIS data (Estimated)

3.3 Characterization of Changes of Rice Planting

In the study site, cropping calendar generally starts from October in harmonized with rainy season. Especially for the northern coastal area where most of paddy field is located in large scale irrigation system, time of rice planting was planned by the local government. However, actual planted time was often modified according to the condition of available water. Figure 6 shows temporal changes of rice planted area indicated by ratio to paddy field area for the period of 2000-2001 to 2008-2009 at Telagasari Sub-District located in the central part of Karawang District. It clearly showed double rice cropping and the time was varied in a range about one month expect for the case of 2000-2001.

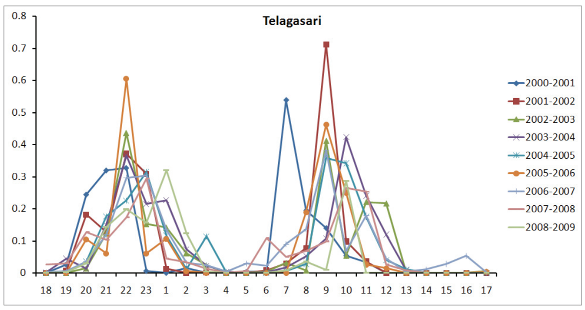

Figure 6. Temporal changes of rice planted area of Telagasari Sub-District

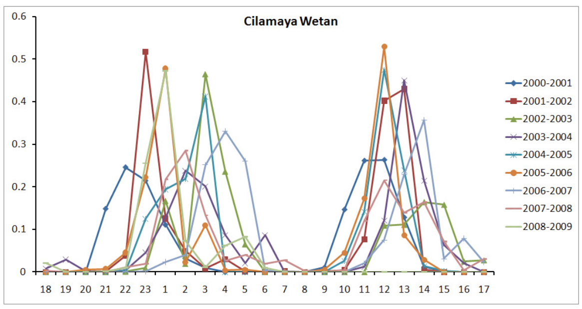

Figure 7. Temporal changes of rice planted area of Cilamaya Wetan Sub-District

Figure 7 shows a case of another Sub-District, Cilamaya Wetan, located at the northeast end of Karawang District. This figure also showed double rice cropping feature but a range of variation was wider compared to the case of Figure 6. The location of Cilamaya Wetan is the lower side of irrigation system, of which water supply tends to be less stable. Therefore, it could be presumed that rice planting time was obliged to be delayed in this area for the case of inadequate storage of irrigation water from rainfall at the beginning of cropping season.

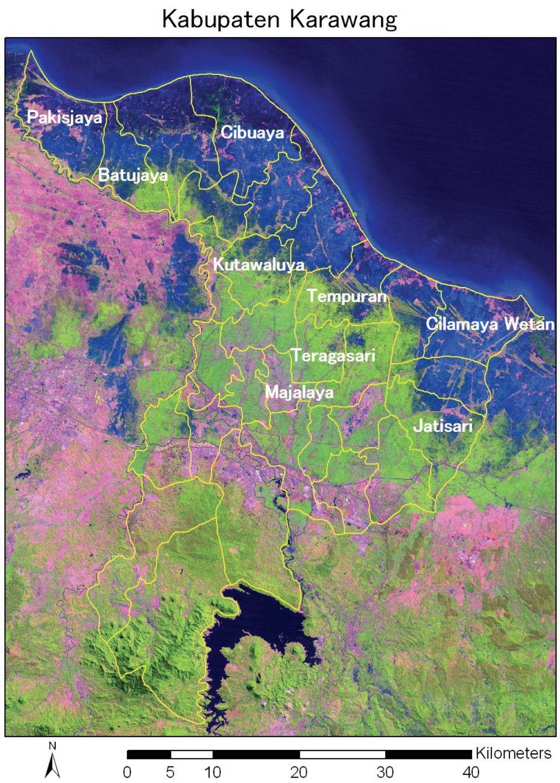

Figure 8. Administrative boundary of Karawang District

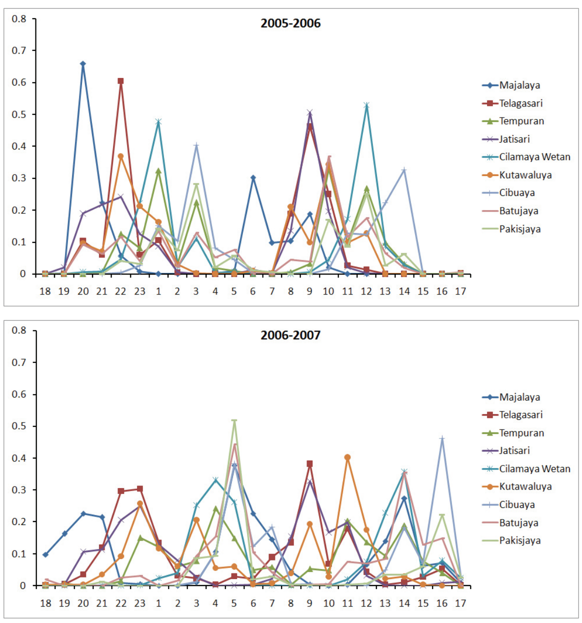

Figure 9. Comparison of pattern of rice planted area between year 2005 to 2006 and 2006 to 2007

The most remarkable difference of time displayed in Figures 6 and 7 was the case of year 2006 to 2007. The next analysis would examine the pattern of changes in that year with spatial context. Figure 8 shows administrative boundary of Sub-District of Karawang District and location of selected Sub-District overlaid on Landsat image. It is recognized that paddy field on alluvial plain extends in the northern half of District.

Figure 9 shows the temporal changes of rice planted area by Sub-District for the 2005 to 2006 and 2006 to 2007. In the year 2005 to 2006, when the rainfall condition was normal, a cascade feature of rice planted area from upper stream to lower stream was clearly indicated. However, in the year 2006 to 2007, when the rainfall was much less than normal, it could be recognized that the rice planted time tended to be late in the lower part. Thus, the temporal and spatial variation of rice planted area could be successfully characterized.

4. CONCLUSIONS

Monitoring of agricultural land use for regional scale is one of the most expecting applications of remote sensing techniques. However, tropical humid climate region is the area of difficulty in this application due to existence of complex cropping pattern as well as high probability of cloud cover. This study proposed a method of land use discrimination using multi-temporal Landsat data and verified its performance for the case of western part of Java, Indonesia. Paddy field area extracted from Landsat data became a base map employed to a scheme of monitoring rice planted time using MODIS data. This scheme brought promising results for analyzing actual spatio-temporal feature of paddy rice planting.

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