

Spatial change analysis of paddy cropping pattern using MODIS time series imagery in Central Java

Muhammad Arif Fatoni^{1*}, Kreshna Dwi Nugroho¹, Alvin Fatikhunnada¹, Liyantono¹, Yudi Setiawan².

¹Faculty of Agricultural Engineering and Technology, Bogor Agricultural University, Fateta Building, 4th, Jl. Kamper, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia

²Center for Environmental Research (PPLH), Bogor Agricultural University, PPLH Building, 2 nd - 4 th, Jl. Lingkar Akademik, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia

E-mail: muhammadariffatoni@yahoo.co.id

Abstract: Central Java had the diverse paddy field cropping patterns and it was influenced by several factors such as water availability, land condition, paddy fields ownership, and local culture. This research was aimed to analyze dynamic changes of paddy cropping pattern using MODIS imagery (MOD13Q1 16-day composite from 2001 to 2015). This research used k-means clustering algorithm for classified cropping pattern in Central Java based on similarity pattern of annual data from vegetation index. The result of this research classified cropping pattern become a main class and produced 15 maps of distribution cropping patterns (from 2001 to 2015). The result also divided Central Java's paddy fields become 2 section (constant and change) based on cropping pattern that majority was caused by water availability. This research got the better accuracy (77.67%) of cropping pattern than long time series analysis from previous research. Although some classes successfully obtained upon annual time series analysis, MODIS still difficult to detect mixed crop pattern.

1. Introduction

Satellite technology for detecting land cover change has been used in several researches for the advancement of precision agriculture. Characteristics of spectral reflectance from vegetation were affected by the leaf pigment content, organic matter, water and leaf structural characteristics such as the shape of leaves and leaf area [1]. The spectral characteristics of vegetation could be divided into the visible spectrum and the infrared spectrum which could be combined to form vegetation index. According to Danoedoro [2], a vegetation index is a form of mathematical transformations involving multiple channels at the same time giving a new image that is more representative of presenting the changes in vegetation. Rice plants which were the majority staple food in Indonesia had the fields area that centralized in Java Island and could be detected using MODIS (moderate resolution imaging spectroradiometer) EVI (enhanced vegetation index) imagery. Setiawan [3] assessed Java's Paddy Fields became 8 specific types and produced distribution map by annual cropping intensity. Moreover, Muhammad [4] used a more specific object that was East Java for analyzing paddy fields dynamic land use. They used long time series MODIS EVI and showed paddy fields land use dynamic in Java



region which happened in the last 15 years. The changes that could be occurred in every time and everywhere in Java region should be detected and analyzed because the changes of paddy cropping pattern could affect the paddy productivity. Many methods were used and developed to get the better result for paddy fields problem solving. Some of the research focused on a spatial problem (pixel of satellite image), and the others modified the method to process time series data. This research focused to analyzed the annual change, and it was intended to support the development of near real-time monitoring in the future. Central Java as the central Province in Java Island had the diverse paddy field cropping patterns and it was influenced by several factors such as water availability, land condition, paddy fields ownership, and local culture. This research analyzed the spatial change of cropping patterns in Central Java and produced the changes distribution map using annual time series MODIS EVI.

2. Methodology

2.1 Study Area

Central Java was located at $8^{\circ} 30' - 50^{\circ} 40' S$ and $108^{\circ} 30' - 111^{\circ} 30' E$ (figure 1) and had the area about 3254412 ha with the paddy fields area about 952525 ha at 2013[5]. Central Java which had 29 District and 6 City is the central Province in Java island. Setiawan[3] explained that Java Island comprises the most active volcanic island in the world, therefore it provides vast areas of fertile soils, which support intensive agricultural lands. The combination of high rainfall rate and fertile soils make many areas of the islands ideally suited for agriculture.

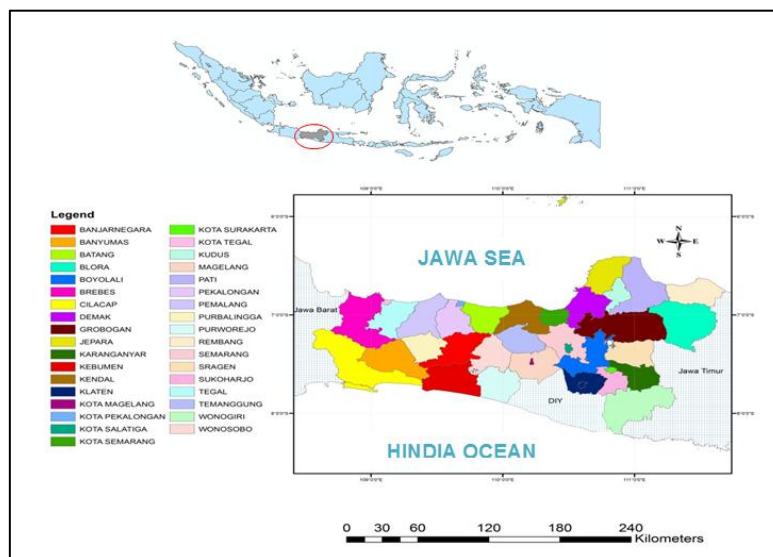


Figure 1. Central Java Province

2.2 Data

MODIS EVI (MOD13Q1) was provided for biomass change analysis and it was corrected from radiometric disruption in atmosphere, gas and aerosol scattering, and more sensitive to high biomass change. MODIS provided 16 composite images with the 250m spatial resolution. It was needed 23 images for representing one-year paddy crop phenology. MODIS EVI was expressed in an equation[6]:

$$EVI = G \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + C_1 \times \rho_R - C_2 \times \rho_{blue} + L} \quad (1)$$

Where, ρ_{NIR} , ρ_R , and ρ_{blue} are reflectance from near-infrared, red, and blue wave from electromagnetic energy, L (1.0) is a soil adjustment factor, C_1 (6.0) and C_2 (7.5) are aerosol scattering coefficient for blue band correction. This algorithm was optimization from NDVI (normalized difference vegetation index) which can't distinguish the change of vegetation index in the high biomass area. We used 23 MODIS EVI data for interpreting annual patterns, so we needed 345 MODIS images to produced annual patterns from 2001 to 2015. The method is describe in figure 2.

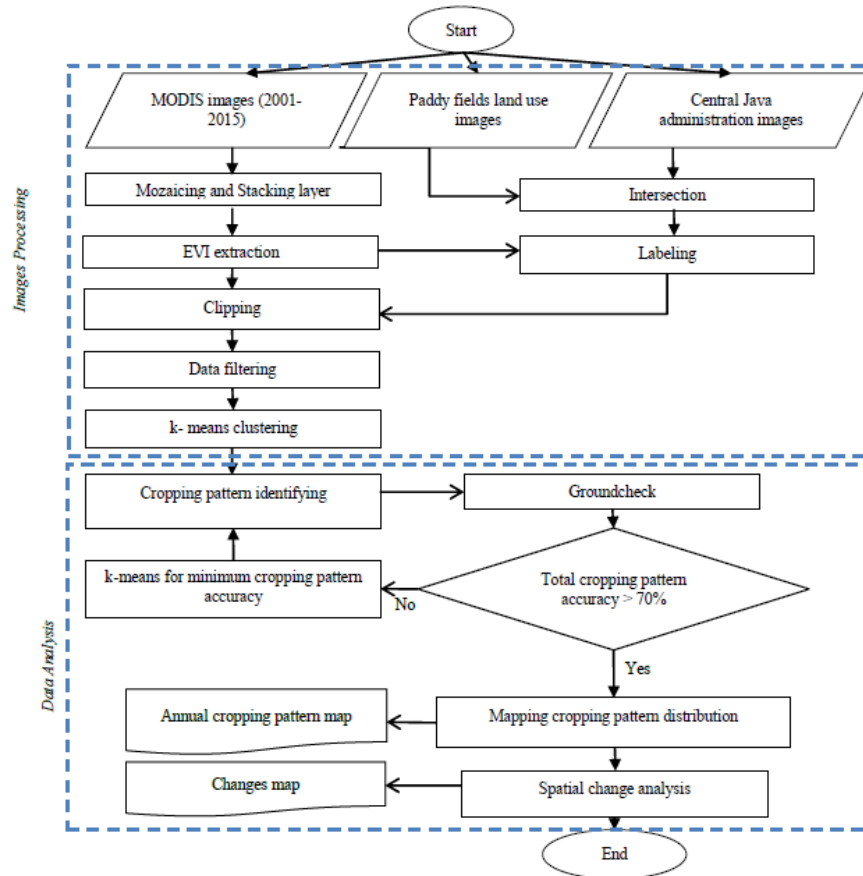


Figure 2. Research method

2.3 Data denoising

Temporal pattern of EVI still had the noise that couldn't be erased by EVI algorithm, and it will be filtered by wavelet transform. This small wave was generally used for MODIS noise reduction process in several previous researches like Setiawan [3] and Muhammad [4] that utilized MODIS EVI for analysis paddy fields in Java region. Sakamoto [8] conclude that the wavelet transform gave the best time profile of EVI for establishing crop phenology. The function of wavelet transform was expressed as follow:

$$Wf(a, b) = \int_{-\infty}^{+\infty} f(x) \frac{1}{\sqrt{a}} \Psi \left(\frac{x-b}{a} \right) dx \quad (2)$$

where a is a scaling parameter, b is a shifting parameter, and Ψ implies a mother wavelet [8]. Because MODIS EVI was discrete data, this study used discrete wavelet transform (DWT) for filtering temporal EVI data that the scaling and shifting parameters transformed as follows:

$$(a, b) = (2^j, 2^j k) \quad (3)$$

Scaling and shifting were two key parameters of the wavelet transform. DWT decomposed a signal into the different scale and through the signal into low pass filter (LPF) and high pass filter (HPF). Setiawan [7] explained these filters retain the large and small scale components of the signals also known as the approximation (A) and detail (D) series, respectively. This study used Coiflet mother wavelet for filtering MODIS EVI signal because previous researches (Muhammad [4] and Setiawan [7]) gave the good accurate for cropping pattern in Java region with the Coiflet mother wavelet. This wavelet shape also gives remarkably good results in determining phenological stages as pointed out by [8]. This study used DWT with Coiflet order 1, level 1, and approximation 1. The level number was representing the decomposition level that has two component, there are the approximation (A1) and detail (D1). Setiawan [7] explained that the function of the level 1 decomposition was $F(t) = A1 + D1$, and then A1 was decomposed into A2 and D2 using LPF and HPF filtered in decomposition level 2. So, there are 3 component results from level 2 decomposition: A2, D1, and D2. This research used decomposition level 1 and approximation 1 (app1) that mean A1.

3. Result and Discussion

3.1 Cropping Pattern Classification

The annual filtered patterns were classified into 25 classes using k-means clustering. The number of the class was determined based on previous research in the Java region and 25 class is the near maximum number of categories that could be discriminated effectively; identification of other categories would likely be difficult to achieve [7]. K-means algorithm classified similar patterns become one class with the number of class was determined. Then, 25 classes were identified and classified into main classes in every year. Each year had the difference total of main classes, that mean it could be increased or decreased every year. For example, there are 12 main classes at 2015: Paddy-Paddy-Bare (PPB), Paddy-Bare-Paddy (PBP), Paddy-Secondary Crop-Bare (PPLB), Paddy-Paddy-Paddy (PPP), Paddy-Paddy-Secondary Crop (PPPL), Paddy single crop in mixed time cropping (P1), Paddy double crop in mixed time cropping (P2), Mixed crop (C), Forrest dominant (H), Pond dominant (T), Housing dominant (Pr), and Bare-Paddy (BP). It is not same with the total of main classes at 2014 that only have 11 main classes because there is no BP class on this year. It means that BP just the particular class which happened in 2015 as a result of changes cropping pattern (it can be abrupt, seasonal, stable, or gradual). The main classes were divided by two: clear class and mixed class. A clear class is the class that has same plant and planting schedule, so the pattern was clear between peak and valley (PPB, PBP, PPLB, PPP, PPPL, BP).

The accuracy of this cropping pattern was approach by confusion matrix (Table 1), which compared with ground check data. Amount 103 reference point in Central Java considered representing the main class for ground check. The total accuracy of this research (77.67%) was better than Setiawan [3] and Muhammad [4] which has the accuracy 74.43% and 71.11% with the long time series analysis. It means that annual time series analysis gave the better result for Pattern recognizing using MODIS EVI data. The difference accuracy also determined several factors like amount of reference point, how they classified the main class, and the variance data of the class. Although there was difference accuracy (77.67%, 74.43%, and 71.11%), the accuracy above 70% is the good accuracy, considering that MODIS had the moderate resolution (250m).

Table 1. Confusion matrix of cropping pattern in Central Java

Cropping pattern	PPB	PBP	PPLB	PPP	PPPL	P1	P2	C	H	T	Pr	User accuracy (%)
PPB	12	0	0	0	0	3	0	0	0	0	0	80
PBP	0	3	0	0	0	0	0	0	0	0	0	100
PPLB	0	0	10	0	0	0	0	0	0	0	0	100
PPP	0	0	0	9	2	0	1	0	0	0	0	75
PPPL	0	0	0	7	14	0	0	0	0	0	0	66.67
P1	0	0	0	0	0	8	1	0	0	0	0	88.89
P2	0	0	0	0	0	7	12	0	0	0	0	63.16
C	0	0	0	0	0	1	1	8	0	0	0	80
H	0	0	0	0	0	0	0	0	1	0	0	100
T	0	0	0	0	0	0	0	0	0	2	0	100
Pr	0	0	0	0	0	0	0	0	0	0	1	100
Procedural accuracy (%)	100	100	100	56.25	87.50	42.11	80	100	100	100	100	100
Total accuracy (%)	77.67											
Total data	103											

3.2 Annual change

This research produced annual distribution cropping pattern maps for analyzing the changes of paddy fields land use in Central Java. The cropping pattern distribution maps can be seen in **Error! Reference source not found.** Spatial analysis was done to know where and when the changes happened based on the color change from cropping pattern distribution maps. From **Error! Reference source not found.**, we know that the cropping pattern changed annually. The map also presented the majority of cropping pattern in an area or District. The majority of cropping pattern was affected by water availability, land area, paddy fields ownership, and local culture. Paddy fields ownership and local culture could affect the cropping pattern in Central Java because the smaller paddy fields area which owned by farmers increasingly diverse the plant and planting schedule in one pixel. When each farmer planted difference crop, the temporal EVI pattern will be mixed. The others two factors (water availability and land area) are the factors which came from nature. The paddy fields that had the location near water sources like reservoir or lake would get more water support for irrigation, so they could grow rice in the dry season. The place that had the PPP (Paddy-Paddy-Paddy) cropping pattern marked in green as Karanganyar, Klaten, Sragen, and Wonogiri region which were close to Gajahmungkur reservoir or Kedungombo reservoir. From this fact, we know that water availability and the land area could affect the cropping pattern.

The area of cropping patterns every year didn't always remain, they can be increased or decreased. It will automatically affect harvest area in Central Java. Figure 3 give an estimation of harvest area in Central Java using MODIS images which were compared with harvest area from Statistics of Indonesia [11]. The estimation of harvested area was obtained by regional measurements using QGIS. From Figure 3 we know that there were several years (2010, 2011, 2014, 2015) which had quite a big difference between MODIS data and BPS data. Based on data reported by [12], from July 2010 until the end of 2011 there was La Nina phenomenon. In the western equatorial region like Indonesia, There would be the formation of more clouds than usual, so it automatically caused a lot of disturbance for MODIS images. It would scatter EVI value that should be patterned rice planting, so the pixel didn't count as rice harvest. Otherwise, from the end of 2014 to round 2015, there was El Nino phenomenon. Each farmer would plant rice with not uniform time because they tend to grew paddy when it rains (El Nino make the rainy season less than usual). Consequently, EVI temporal patterns became docked and difficult to distinguish between one or twice planting.

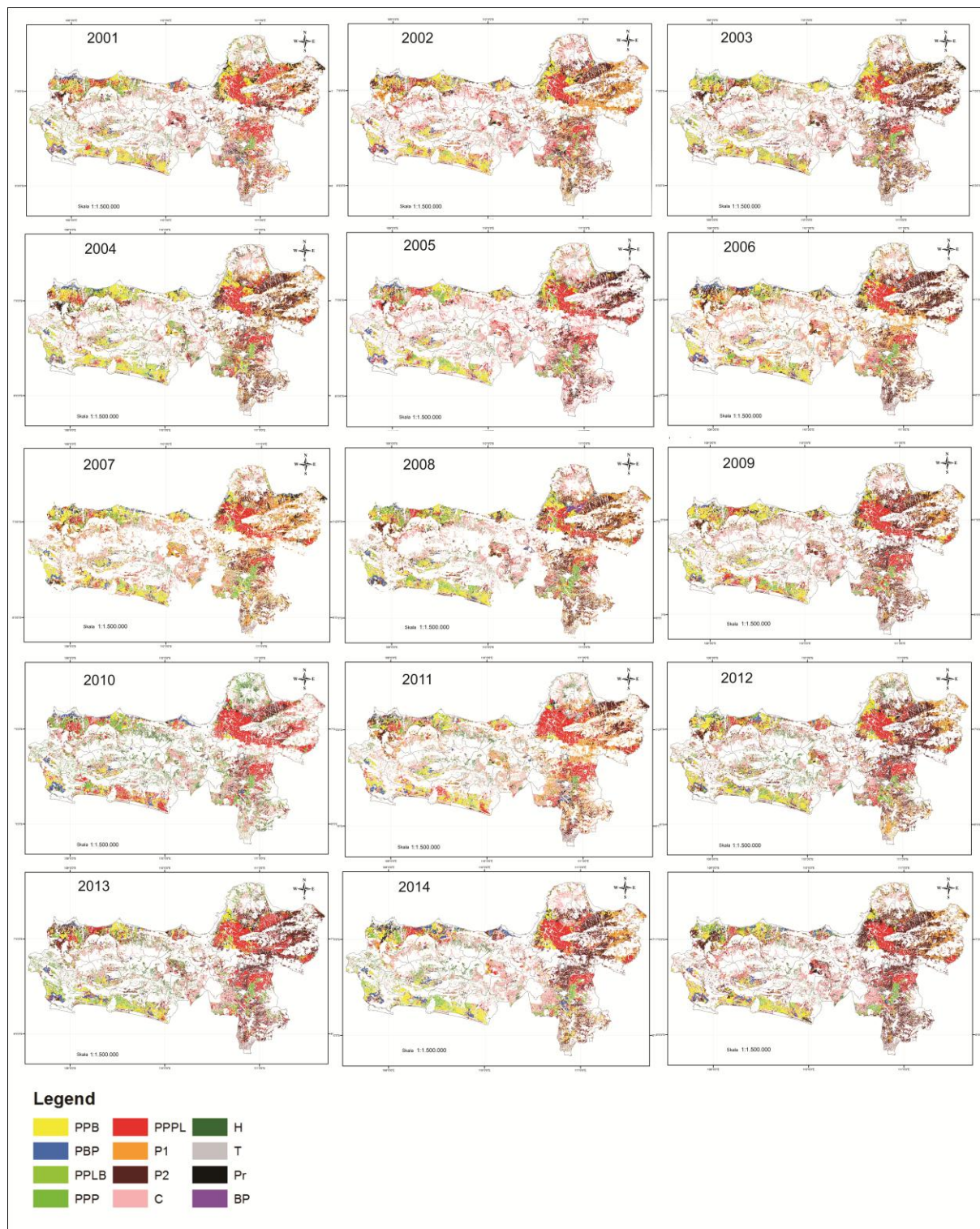


Figure 3. Annual distribution cropping pattern maps in Central Java

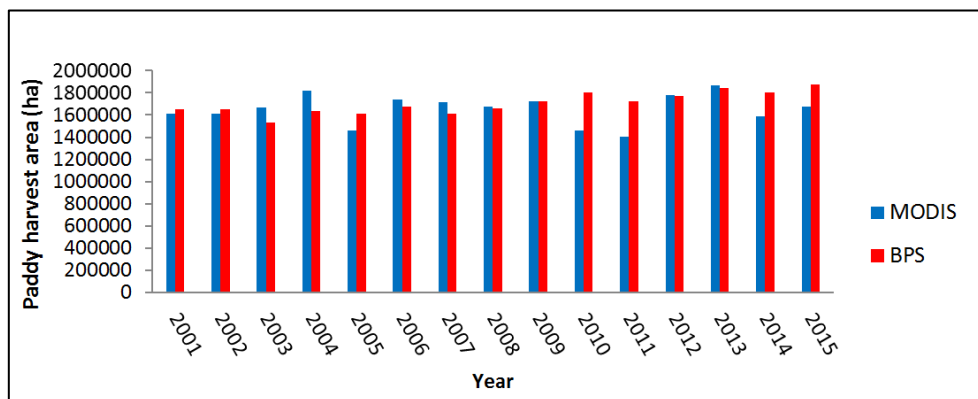


Figure 3. Paddy harvest area from MODIS and BPS

3.2 Change analysis

The change of paddy cropping patterns could be detected by clipping the annual cropping pattern map. The changes could be abrupt, seasonal, stable, and gradual. The spatial analysis had the objective for discussing where, when, and what was the changes happened. **Error! Reference source not found.** give the example gradual change that happened from 2001 to 2015 in Central Java that was decreasing of the area with the PPB pattern and gradually became PPPL every year. This changes happened in Undaan, Kudus District. Abrupt changes also happened in the beginning of 2008 that BP pattern suddenly widespread in Undaan, Kudus. The Bare-Paddy pattern indicated that there was a bare area at the beginning of the year. It could be caused due to flooding which happened in 2008. The stable changes also happened from PPB cropping pattern became PPPL cropping pattern start from 2009. The differenced types of change (abrupt and stable) could happen from difference factors. Abrupt changes are normally caused by disturbances such as fire, flood, urbanization, insect attack, or drought [9]. While stable changes usually occurred by water availability or the changes of cropping pattern culture.

The land cover change dynamic analysis produced the information about the stable cropping pattern map and shows in f. There were about 1262976.26 ha (5.2%) paddy fields that haven't change in last 15 years. This fact indicated that majority of paddy fields in Central Java ever changing cropping pattern. From Figure 4, we know that majority stable cropping pattern was PPPL (red color) pattern which gathered in Kudus, Demak, and Grobogan District. Paddy fields at those regions were not irrigation type, and according to [2] was paddy double cropping area. Based on ground check, the farmer prefers to plant secondary crops in dry season. This is also corroborated by the rainfall data in Kudus from 2011 to 2015[10] which had the small rainfall at June until October. The rainfall not enough to irrigated rice crops in that period.

These maps give the main information that Central Java always changing their cropping pattern and just little area that stable with their cropping pattern. This picture seemed to give the message that the near real-time monitoring system was very important for assessed this phenomenon. The majority of paddy fields area always changed each period, or the map explained that majority of paddy fields in Central Java was not stable. Variation of the changes time indicated the change was affected by time period. It could be from rainfall influence, topography (land area), or farmers habit (culture and ownership). It difficult for concluding the cause of changes, because the variation culture and large area for analysis made it became the complex problem.

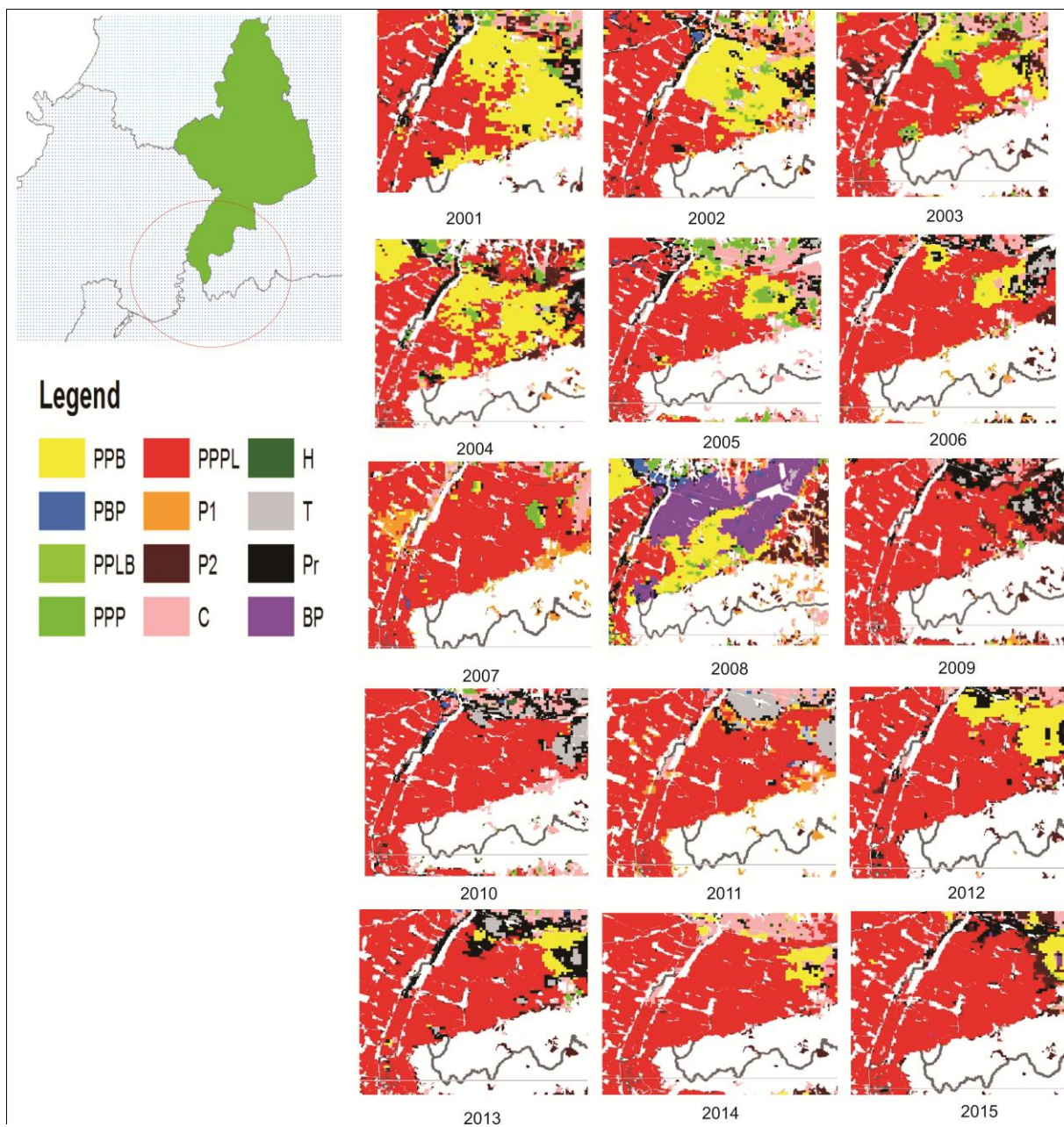


Figure 5. Gradual change in Undaan, Kudus District

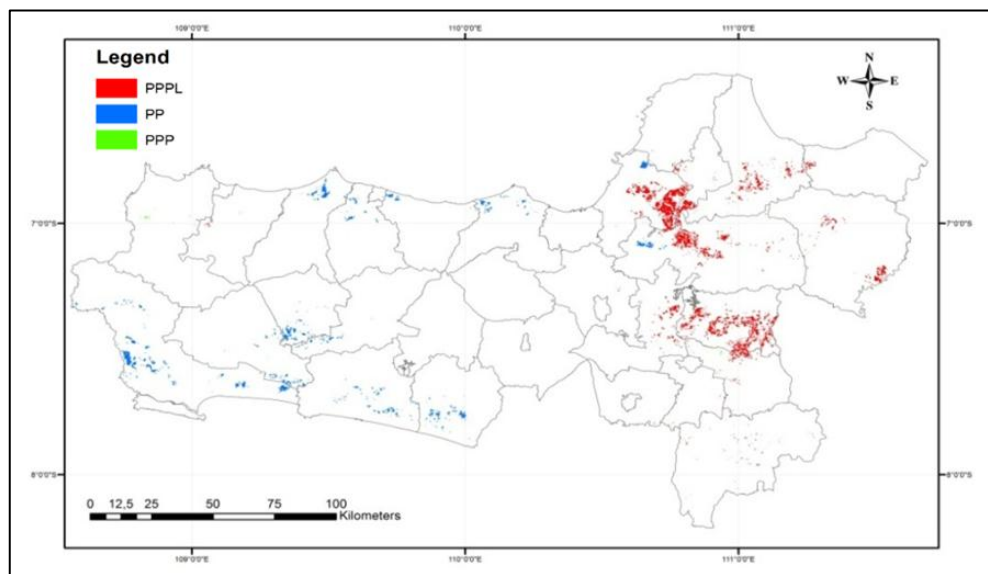


Figure 4. Stable cropping pattern map in last 15 years

4. Conclusion

This research got the better accuracy (77.67%) of cropping pattern than long time series analysis from Setiawan [3] and Muhammad [4]. Although some classes successfully obtained upon annual time series analysis, MODIS still difficult to detect mixed crop pattern. Spatial change in Central Java could be detected by annual time series analysis of MODIS EVI. The changes divided into abrupt, seasonal, stable, and gradual. Using annual data analysis, the spatial changes was more represented. The majority of paddy fields area (94.8%) in Central Java ever changing their patterns in last 15 years. Variation of the changes time indicated the change was affected by time period. Paddy double cropping pattern (PPPL and PP) was more stable than paddy triple cropping pattern (PPP). it means that Paddy in the dry season was only slightly which consistent for last 15 years. The changes could be affected by drought, flood, urbanization, or insect attack. The result of this research seemed to give the conclusion that paddy fields near real-time monitoring system was needed for distribution of more precise and accurate information.

Acknowledgments

The authors would like to thank the Center for Environmental research (PPLH-IPB) for facilitating this research. Gratitude also gives to NASA LP DAAC, Indonesian Geospatial Information Agency (BIG), and Indonesian central statistics agency for providing data of this research.

5. References

- [1] Huete A and Glenn E 2011 *Remote Sensing of Ecosystem Structure and Function, Advance in Environment Remote Sensing* (Boca Raton (USA: CRC Press)
- [2] Danoedoro P 2012 *Pengantar Penginderaan Jauh* (Yogyakarta, Indonesia : ANDI)
- [3] Setiawan Y, Rustiadi E, Yoshino K, Liyantono and Effendi H 2014 Assessing the seasonal dynamics of the Java's paddy field using MODIS satellite images *ISPRS Int. J. Geo-Information* pp 110-129
- [4] Muhammad M, Liyantono, Setiawan Y and Fatikhunnada A 2015 Prediction of paddy field cropping pattern using time series MODIS image in East Java *Proc. Int. Symp. on Geoinformatics* pp 36-40
- [5] Badan Pusat Statistik 2013 *Paddy fields area of Indonesia 2003-2013* (Jakarta, Indonesia: Pusat Data dan Sistem Informasi Pertanian)

- [6] Huete A, Didan K, Miura T, Rodriguez E P, Gao X and Ferreira L G 2003 Overview of the radiometric and biophysical performance of the MODIS vegetation indices *Remote Sensing of Environment* **83** pp 195– 213
- [7] Setiawan Y, Yoshino K and Philpot W D 2013 Characterizing temporal vegetation dynamics of land use in regional scale of Java Island, Indonesia *Journal of Land Use Science* **8** pp 1–30
- [8] Sakamoto T, Yokozawa M, Toritan H, Shibayama M, Ishitsuka N and Ohno H 2005 A crop phenology detection method using time-series MODIS data *Remote Sens. Environ* **96** pp 366–374
- [9] Kawabata A, Ichii K and Yamaguchi Y 2001 Global monitoring of interannual changes in vegetation activities using NDVI and its relationships to temperature and precipitation *Int. journal of remote sensing* **22** pp 1377-1382
- [10] Badan Pusat Statistik 2015 *Monthly of rainfall in Kudus District 2011-2015* (Jakarta, Indonesia: Pusat Data dan Sistem Informasi Pertanian)
- [11] Badan Pusat Statistik 2015 *Paddy harvest area 1993-2015* (Jakarta, Indonesia: Pusat Data dan Sistem Informasi Pertanian)
- [12] National Oceanic and Atmospheric 2015 *Data of oceanic nino index* (Marryland, United States: Center of Weather and Climate Prediction)