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LAND USE ANALYSIS USING TIME SERIES OF VEGETATION INDEX DERIVED FROM SATELLITE REMOTE SENSING IN BRANTAS RIVER WATERSHED, EAST JAVA, INDONESIA

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Abstract: *In this study, time series datasets of MODIS EVI (Enhanced Vegetation Index) data from 2002 and 2011 in the Brantas River watershed located in eastern Java, Indonesia were analyzed and classified to make ten land use maps for each year, in order to support watershed land use planning which takes into account local land use and trends in land use change. These land use maps with eight types of main land use categories were examined. During the 10 years period, forested area has expanded, while upland, paddy rice field, mixed garden and plantation have decreased. One of the reasons for this land use change is ascribed to tree planting under the joint forest management system by local people and the state forest corporation.*

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1. INTRODUCTION

The sustainability of regional environment and society has become an important issue due to the effects of global warming being recognized throughout the world (Parry et al., 2007). Regional land use is easily affected not only by global warming but also socio-economic development and population growth (Kaneko et al., 1998). On the other hands, land use itself affects global environment and regional-global climate (Foley et al., 2005). Examination of regional land use over a long period of time is useful to determine any changes in the natural environment and society and to understand the trends in these changes, causes and processes (Himiyama & Okamoto, 1992).

In regions where large-scale irrigation development projects such as dams, irrigation canals and so on all over the world (JICA, 2011) have been carried out, the projects have affected both regional society and the natural environment, since infrastructure development induces socio-economic development, then urbanization begins in the region. Generally, urbanization affects both regional society and environment. Monitoring regional land use over a long period is helpful to study the sustainability of natural environment, society and development projects (Ramankutty & Foley, 1999).

Water infrastructure in Indonesia had been developed since the Dutch Colonization period, in order to avoid floods and to build irrigation system. Many of the infrastructures for irrigation and drainage constructed by these projects have remained and are still in use and providing social services to the region (Pasandaran, 2007). These large-scale developing projects under some urban policies on regional development could actually have affected regional environment (Amato et al., 2016). Indonesia is a suitable area to study sustainable agricultural development and future land use against global climate change. That is how they can modify their regional development plans in future, because they have a very long history of regional development for longer than one hundred years, especially in the areas or watersheds where regional socio-economies have been rapidly growing. These areas are thought to be dramatically changing due to the expansion of urban areas or agricultural land development by increasing population. In these areas, the newly developed lands have been expanding following the land use plans of the local government and also by illegal development. In order to control this illegal development, the characteristics of regional land use patterns and their changing trends should be understood in order to propose some applicable land use plans for watersheds and also to have better sustainability of the global ecosystems and human beings (Foley et al., 2011).

Brantas watershed is the biggest watershed in East Java Province (BBWS Brantas, 2011). However, the local environmental agency indicated that vegetated lands in this watershed are under pressure, especially in upstream areas. Many existing land use allocations are inconsistent with spatial land use planning, even though the government rules, namely the Law No. 26/2007 on spatial planning and Law No. 41/2000 on basic forestry law, are stating that at least 30% of the area has to be allocated to vegetated land, such as garden and forest (BLH Prov. Jawa Timur, 2009). Based on these reports, it could be estimated that the agricultural lands or residential lands have disorderly invaded into the natural land use such as forest land. As a result, the forest environment has been degraded. The land use in this area could be intently changing to agricultural lands.

The objectives of this research were, 1) to create annual land use maps of the Brantas River watershed in eastern Java, Indonesia from 2002 to 2011 using time series MODIS EVI data applying a wavelet de-noise filter, and 2) to study the characteristics of regional land use patterns and trends in land use change. This paper contains five chapters. After mentioning the backgrounds of this research, data and methods used in this research are described in the chapter 2. In the chapter 3, the results of land use mapping for 10 years in Brantas watershed using time series MODIS EVI data are given. In the chapter 3, we also discuss about land use patterns in this area and land use change during these 10 years. Finally, in the chapter 4, we conclude our findings resulted in this research.

2. DATA AND METHODS

2.1. Study site

Brantas River watershed located in the eastern part of Java, Indonesia (Figure 1) and has a tropical monsoon climate. The annual average air temperature from 1996-2000 and the annual average precipitation are 25.12 degrees Celsius and 1,876 mm/year, respectively (Widianto et al., 2010; WMO, 2013). Its area comprises approximately 12,000 km^2 and Surabaya city is situated at the mouth of Brantas River, the second largest city in Indonesia with population of about 3 million. It is a famous agricultural area. Most of the land use types are: forest, plantation, mixed garden, rice paddy field, and uplands. Triple-rice cropping is undertaken in this watershed (Haruyama, Ooya, & Mizuhara, 1992). Recently, the socio-economic situation in this watershed has rapidly risen along with an increasing population (Bhat, Ramu, & Kemper, 2005). Therefore, rational land use and sustainable environmental planning are necessary (JBIC Institute, 2008).

The downstream area of Brantas River has frequently suffered from flooding such as the large flood occurred in 2010. The flooding caused damage to crops, inability to cultivate land due to water logging of soils, disruption of settlement, transportation and loss of property. To counter these problems, many flood control projects have been carried out by the Indonesian government since the 1950's as well as other large scale flood control projects such as construction of big dams and irrigation-drainage projects under Japanese-aid (JICA, 2011). However, in spite of these projects and the forest management policy of Indonesia's government, floods have frequently occurred (Hidayat, 2009). In addition, dynamics changes of forest cover are found in forested areas (Setiawan, Yoshino, & Prasetyo, 2014), and sedimentation on the river floor has become severe (Adi, Jänen, & Jennerjahn, 2013; Widianto et al., 2010). It is therefore assumed that there are other reasons for frequent floods. The characteristics of land use patterns and the trends in land use change in this watershed should be understood in detail to facilitate rational watershed management and sustainable agricultural development.

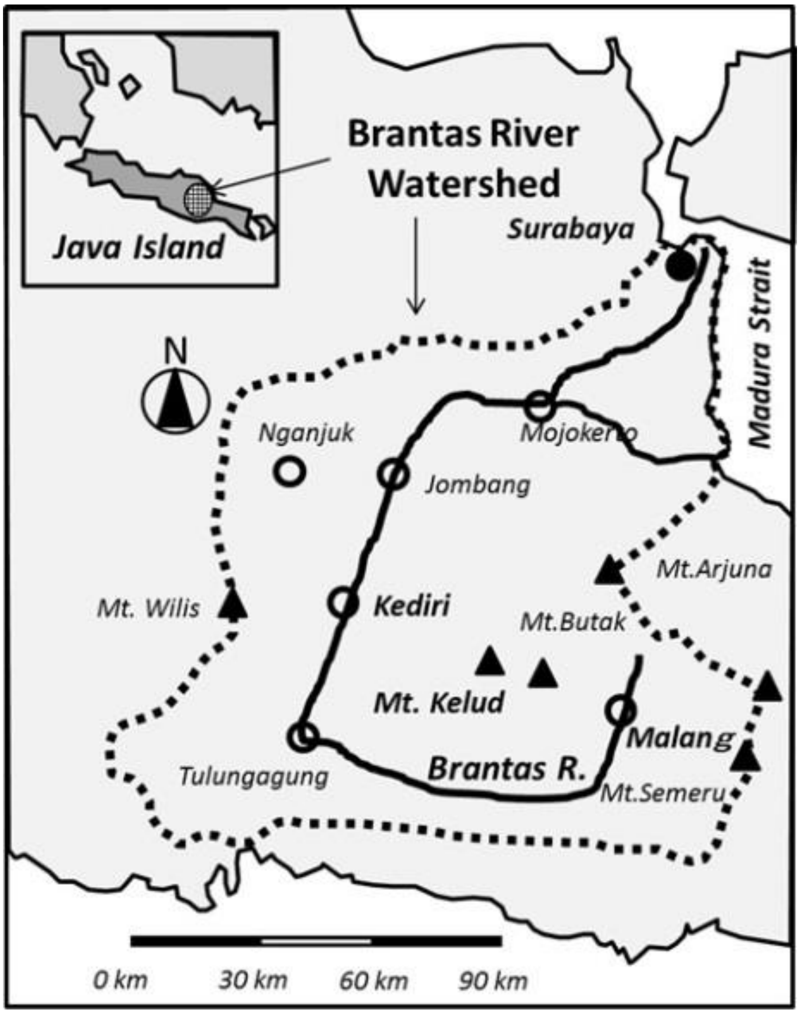

Figure 1. Outline map of Brantas River watershed

2.2. Remotely sensed imagery in this study

Monitoring land use precisely changes in large regions over a long period of time and to carry it out in detail is generally difficult. Recently, satellite optical remotely sensed images are used to study land use and land cover both on a global scale and in regional scale (Di Palma et al., 2016). However, there are some shortcomings in applying this method to tropical regions where the cloud coverage rate is high (Setiawan, Yoshino, & Philpot, 2013). Time series MODIS (MODerate resolution Imaging Spectroradiometer) data recorded by two earth observation satellites, Terra and Aqua, are valid to obtain land use and land cover change over a global scale or regional scale (Friedl et al., 2002; Sakamoto et al., 2006). These two satellites observe the whole surface of the earth twice a day. Secondary MODIS datasets that were processed from observed data for specific purposes are open to the public and can be downloaded via the internet (LPDAAC, 2013a). These datasets provide information on the condition and dynamics of the earth surface such as land use/land cover in short time intervals.

The time series MODIS EVI (Enhanced Vegetation Index) produced from the observed data were used in this study. The datasets are referenced as H29V9 of MODIS Sinusoidal Tiling System (LPDAAC, 2013b) and cover the study site. The 230 scenes of MODIS EVI datasets, MYD13Q1 (LPDAAC, 2013d) observed from July 2002 to June 2012, a period of 10 years. The 16-days composite data with the spatial resolution of 250m were downloaded from the NASA's web-site (NASA, 2013). These datasets comprising point data of MODIS original scenes for 16 days as the probability for cloudless observation of the ground is considered optimal during this time period.

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EVI is one of the vegetation indices developed by Huete et al. (2002). It was computed using band data from the visible blue band, visible red band and infra-red band. It reduced the effects of variation in the sun irradiance, thin cloud or cloud shadow, topographic effects, sun elevation and view-angle effects. Moreover, atmospheric effects such as scattering and absorption are removed as it uses visible blue band data. However, additional data processing is necessary, since datasets from tropical regions are affected by cloud noise (Solano, Didan, & Jacobson, 2013).

2.3. Procedures for data processing

The 230 scenes of MODIS EVI 16-days composite datasets for the 10 years were aggregated and analyzed as follows. Every processing algorithm is standard and popular in order to analyze satellite remote sensing data.

[1] Reprojection of each image using MRT (LPDAAC, 2013c): an application was used for reprojection of datasets from the MODIS original projection system to WGS-84 geographical projection system. For computation of area of land use, images were reprojected to UTM coordinates system zone 49S and resampled at every 250m. At the same time, the QA (Quality assurance) of each dataset was validated.

[2] De-noising of the aggregated dataset: In order to remove the spike-like noises per pixel from the time series data in the aggregated dataset, a wavelet transformation filter was applied to the time sequential EVI of every pixel in the aggregated dataset using MATLAB wavelet tool (Mathworks, 2009), then a smooth time sequential EVI dataset was obtained. The wavelet model was the Coiflet model, the same model used by Sakamoto et al. (2006). The order 2 for the wavelet was applied in order to retain the original characteristics of the data. This de-noised time sequential data was divided into 10 datasets corresponding to each year.

[3] Supervised classification for land use mapping: The de-noised image of the base year was classified with a supervised classification algorithm using reference training data.

[4] Computation of correlation coefficients (Morita, 1985) between the base year dataset and the target year dataset: A pixel of each one-year dataset is a 23 dimensional vector. The correlation coefficients between pixels of the base year dataset and those of other one-year datasets were computed. The dataset from 2007 was retained as the base year dataset. Later, pixels which had higher correlation coefficients than 0.8 were chosen as training samples for supervised classification.

[5] Statistics of signature of each land use category were computed using the training samples chosen in previous step [4].

[6] Supervised classification for land use mapping: The algorithm of MLH (Maximum Likelihood) supervised classification was applied to map land use, and a land use map of each year was drawn.

[7] Characterization of trends: Using a land use map of each year, the characteristics of land use and the change in this watershed were analyzed and discussed.

3. RESULTS AND DISCUSSION

3.1. Land use categories for classification and land use mapping of the base year

Nineteen land use categories were determined (Table 1) by the previous work (Setiawan, Yoshino, & Philpot, 2013). These 19 land use categories were those that could be selected as training data in this watershed. There were four categories of rice paddy fields, four of upland fields, one mixed garden, five of forest lands, three of plantations, one urban area, and one water surface. They are appropriate land use categories to study land use and land use change in this watershed. Totally 13,723 pixels were selected as the training samples. The de-noised image of the base year, a dataset from 2007, was classified with a supervised classification algorithm using these training data. This land use map in 2007 is used as a base or reference land use map for analysis of datasets of other years. The reason of 2007's dataset selection for creating a base land use map in this study is that a reliable land use map was drawn using satellite images taken in this year (Department of Forestry, 2008).

Table 1. Reclassification of land use categories in this study (analysis, 2015)

Land use category (Setiawan et al., 2013)	Re-classed land use category
1. Triple irrigated paddy field	1. Triple crop paddy
2. Double irrigated paddy field I	2. Double crop paddy
3. Double irrigated paddy field II	
4. Double irrigated paddy field III	
5. Upland	3. Upland
6. Upland with intensive agricultural land	
7. Upland with mixed agricultural land	
8. Irrigated fields	
9. Mixed garden with bush	4. Mixed garden
10. Forest mixed with bush	5. Forest
11. Bush mixed grass	
12. Dryland forest	
13. Heterogeneous mangrove forest	
14. Mangrove	
15. Rubber plantation	6. Plantation
16. Oil palm plantation	
17. Timber forest plantation	
18. Builtup	7. Urban area
19. Pond	8. Water surface

In order to provide a consistent definition for pixel based analysis, we need to resolve the differences among the nineteen land use categories in the dataset. The process of reassigning land use categories based on the knowledge of the each land use characteristic is shown in Table 1. Nineteen land use categories were re-classed into eight categories: triple cropping rice paddy field, double cropping rice paddy field, upland field, mixed garden, forest, plantation, urban area, and water surface. When tabulating an error matrix for evaluation of classification (Richards, 2006), it was found the overall classification accuracy was 71 % for these 8 categories. In consideration of the spatial resolution (250 m) used on this dataset, this land use map is assumed to show a true land use pattern in this watershed around 2007.

3.2. Sampling training data based on the correlation coefficients

In general, strictly selected reference data should be used for supervised classification. Usually, samples are selected by designating several pixels which are thought to be proper training areas of each land use category with several ways such as ground survey, referring reliable land use maps in order to obtain sufficient number of training samples (Oobayasi & Kojima, 2002). However, it is important to collect fine training data for every image to detect land use change in short periods from the results of land use classification in every year.

In this study, training samples were collected by selecting pixels which have higher correlation coefficients than 0.8 between the base year dataset of 2007. The other year datasets where those pixels have the same land use categories as the pixels in the base-year dataset were equally used, because only in 2007, we have a reliable land use map authorized by the Ministry of Forestry of Indonesia. For accessing the similarity of two spectral signatures which are recognized as two vectors of multiple variables, the angle between two vectors is observed as the similarity of two vectors. The smaller angle means that they have high similarity.

The value of COSIN of that angle is equal to the correlation coefficients in terms of the fundamental relationship between geometry and statistics. So, in this research, the correlation coefficients are used to measure the similarity of two vectors of the same pixels of two years. Figure 2 shows the accumulated frequency in percent of the correlation coefficients between each year and the base year dataset of 2007. Although the correlation coefficients of 2010 looks different from those of the other years, over 30 to 45%

of pixels in the other year datasets have correlation coefficients higher than 0.8. Thus, at least over 100 pixels were selected as training samples for each land use category in each year.

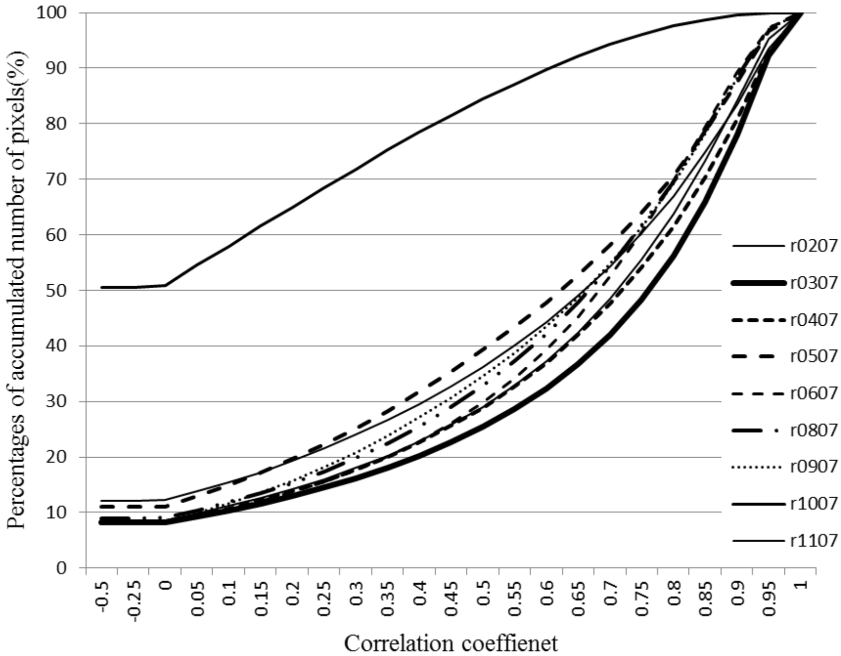

Figure 2. Accumulated histogram of correlation coefficients
(the first 2 digit number in the legend shows the year of interest)

3.3. Supervised classification result

Supervised classification of land use for each year dataset except the dataset of 2007 was conducted with MLH (Maximum Likelihood method) using training samples selected in the former section. As example, the land use classification maps for 2002 and 2011 are shown in Figure 3. In these two land use maps, it is clear that land use in this area has been changed in many places.

In general, rice paddy fields widely spread downstream from Kediri and the mountains are covered with forest. Most lands except rice paddy fields and forest are upland field, mixed garden and plantation. In the coastal area of the eastern part of Surabaya, large fish ponds are expanding. However, they were classified into water surface.

3.4. Land use change from 2002 to 2011

The acreages of each land use category in each year from 2002 to 2011 are shown in km^2, to study the trends of land use change in Brantas River watershed (Figure 4). Variations of acreages in each year are rather large for many land use categories. One of the causes of these large variations of estimated acreages of land use classes is assumed to be attributed to the intrinsic drawback of MODIS composite products. A pixel value is affected by the viewing geometry of MODIS sensor of observation dates which changes the dimension of the pixel on the ground, so that a pixel consists of spectral signals from ground cover conditions or land use of surrounding pixels. This intrinsic drawback leads a fairly large number of misclassification of MODIS composite data (Tan et al., 2006). As this drawback cannot be compensated, we will ignore the uncertainty of classification results in this paper.

Moreover, the previous study in East Java (Muhammad et al., 2016) also mentioned that the mixed pixel issue was an important consideration of land use classification using MODIS data since the classification result of specific land use classes revealed the overall accuracy to be 57.7 %.

Apparently, the forest increased during the past 10 years, while other land use categories such as double cropping rice paddy, upland, mixed garden, and plantation seem to decrease. Water surface, triple cropping rice paddy field and urban area maintained their acreages.

The five years average acreage for each land use category from 2002 to 2006 was compared to those from 2007 to 2011 to summarize the trends of land use changes during the ten years period. As for forest, upland field and single cropping rice paddy field, they have increased to 718, 48 and 5 km^2 in acreage, respectively. By contrast, double cropping rice paddy field, triple cropping paddy field, mixed garden, plantation and urban area have decreased to 345, 130, 124, 112, and 59 km^2, respectively.

Land use categories such as forest, upland field and double cropping rice paddy field showed a rapid change in their acreage on a scale of several tens thousands hectares since 2009 compared to other years. Forest area has increased, on the other hand, upland field and double cropping rice paddy field have decreased. The total annual precipitation of 2,483 mm and 2,274 mm during the period from July, 2009 to June, 2010 and during the period from July 2010 to June, 2011 in Surabaya area, respectively, was the reason of this change. These heavy rainfalls were recorded at the Surabaya meteorological observation station in this period. They were calculated based on precipitation records. These precipitation exceeded the 30 year average annual precipitation of 1,876 mm (WMO, 2013). Due to the natural physiological response of tropical plants against sufficient rainfall, vegetation in this area consequently grew further between 2009 and 2010 than in other periods, so that the annual EVI patterns in this period are understood to show different patterns from those of other periods.

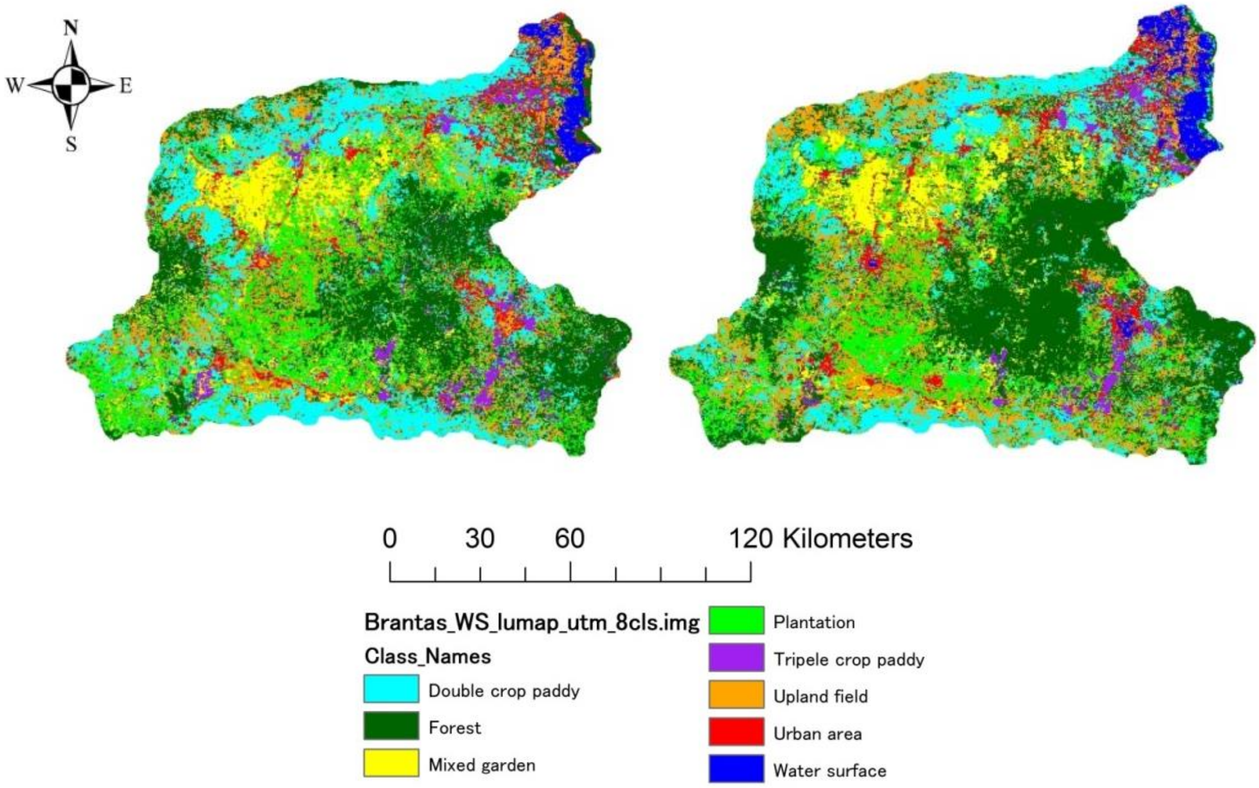

Figure 3. Eight categories land use maps in 2002 (left) and 2011 (right)

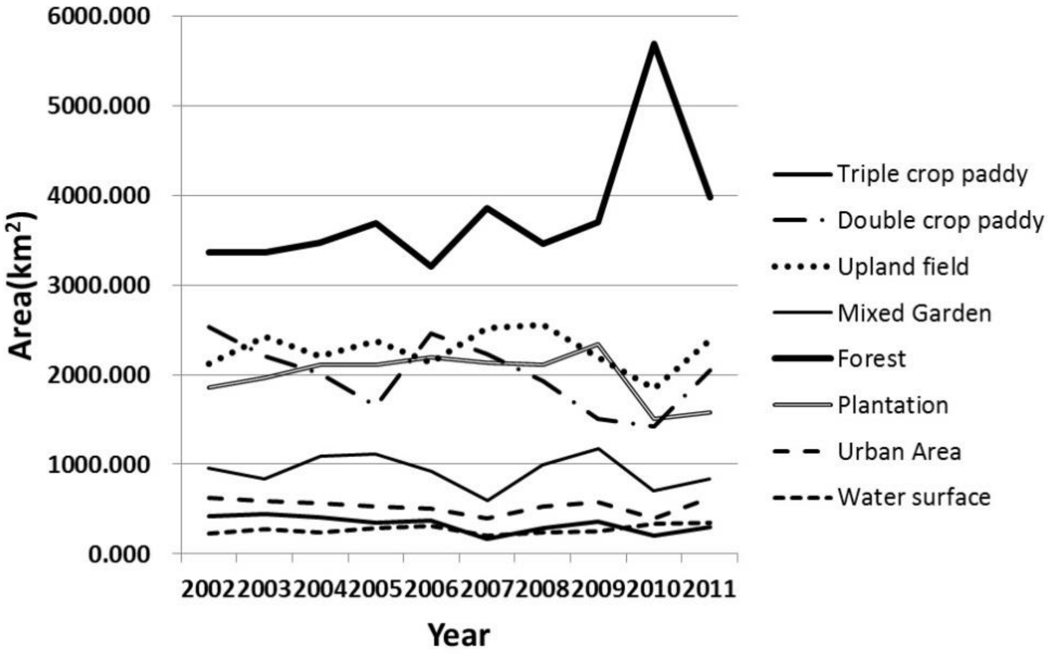

Figure 4. Land use change in Brantas River watershed 2002-2011

3.5. Characteristics of land use change in the watershed

3.5.1. Land use change matrix

Table 2 tabulated the land use change matrix between 2002 and 2011. The rows are the acreage for each land use in 2002, while the columns are those from 2011 in km^2. The values in the diagonal items are unchanged acreages of the same land use categories both in 2002 and 2011. The other items indicate the land use changes from 2002 to 2011. In this table, the conversion of land use from 2002 to 2011 focused on changes more than one hundred km^2; 110 km^2 of triple cropping rice paddy field changed to forest, 490 km^2 of double cropping rice paddy field changed to upland, 457 km^2 to forest, 151 km^2 to plantation and 107 km^2 to urban area.

About 498 km^2 of upland have changed to forest, 321 km^2 to plantation, 236 km^2 to double cropping rice paddy, and 132 km^2 to urban area. Meanwhile, 189 km^2 of mixed garden have been converted into forest, 142 km^2 into plantation, 306 km^2 into upland, respectively. Then, 478 km^2 of forest have been converted into upland, 311 km^2 into plantation, 306 km^2 into double cropping rice paddy field, 577 km^2 of plantation into forest, 391 km^2 into upland, 124 km^2 into mixed garden, 94 km^2 into double cropping rice paddy field, 85 km^2 into forest. Moreover, 17 km^2 of water surface have changed to upland, 10 km^2 to double cropping rice paddy field, 12 km^2 to urban area.

3.5.2. Long term land use change

In order to assess the long term stability of land use from 2002 to 2011, the unchanged land use of every land use category was examined by computing the acreages that did not change between 2002 and 2011 for each land use category (See the last line of Table 2). The total acreage of unchanged lands in 8 land use categories was about 872 km^2. Other lands have temporally or almost permanently changed to other land use. About 219 km^2 of rice paddy field, 477 km^2 of forest, 54 km^2 of mixed garden, 84 km^2 of water surface, 9 km^2 of upland field, 13.1 km^2 of plantation and 15.8 km^2 of urban area respectively have not changed.

Forest distributed on the hillside of Mt. Kelud was unchanged. Unchanged rice paddy fields are seen in flat plain downstream of the Brantas River. Unchanged mixed garden is expanding in the suburban area near Kediri town. Unchanged water surface remains in the tidal area in the river mouth of the Brantas River. Unchanged triple cropping rice paddy fields are recognized upstream of the Brantas River. The unchanged urban area and upland fields are scattered. They are not spatially accumulated.

Table 2. Land use change matrix between 2002 and 2011

Land use in 2002	Land use in 2011								
	Triple crop paddy	Double crop paddy	Upland field	Mixed garden	Forest	Plantation	Urban area	Water surface	Total
Triple crop paddy	139.7	62.1	40.2	21.3	110.7	15.3	21.6	0.1	411.0
Double crop paddy	46.9	1153.4	490.8	96.1	456.6	150.9	106.5	6.4	2507.6
Upland field	21.1	235.8	721.6	69.0	498.1	320.5	131.9	91.4	2089.3
Mixed garden	14.3	61.3	101.7	417.0	188.6	142.1	10.9	0.1	936.0
Forest	57.6	306.3	477.6	88.9	2017.3	311.1	53.4	20.4	3332.6
Plantation	9.1	107.1	391.2	123.8	577.1	601.4	26.9	0.3	1836.9
Urban area	7.2	93.3	116.8	4.2	85.3	19.4	251.3	37.8	615.3
Water surface	0.1	9.8	16.7	0.0	6.0	0.2	12.0	184.9	229.6
Total	296.1	2028.9	2356.4	820.3	3939.6	1561.0	614.6	341.4	11958.3
Unchanged	30.8	188.0	9.1	54.3	477.1	13.1	15.8	83.8	871.9

(Unit km^2)

3.6. Driving forces of land use change

According to the results of land use classification in this study, forest has increased its acreage between the first 5 years and the last 5 years. Furthermore, rice paddy field, upland field, mixed garden and plantation have decreased their acreages 100 km^2 to several 100s km^2. These results are contrary to expectation which was described in the introduction. As for the increase of forest, it is assumed that afforestation projects conducted by community based forest management system (CBFM) under the forest management system promoted by *Perhutani* Indonesia are working well to conserve the forest environment (Asia Forest Network, 2004). The fact that forest in this area has been steadily increasing indicates that the regional environmental policies in this watershed have begun to show their effects to regulate land use pattern and to mitigate the imprudent land development (Amato et al., 2016). Since the increase of forest in the hillside reduces the surface soil loss rates from the sparsely vegetated lands to the river, soil suspension of the river water could get lower, then, the sedimentation on the river floor in the river streams would decline (Yoshino & Ishioka, 2005). Consequently, the frequency and the severalty of flooding of Brantas River will decrease in the near future.

Additionally, contrary to our expectation that the forest lands have intently decreased, the urban area did not significantly expand during the 10 years. One possible reason for this is that the spatial resolution of MODIS EVI, which is 250 m x 250 m, is too large to detect urban change. The small changes in urban area could be buried in this large spatial resolution of MODIS data. In order to detect area and location of such kinds of small scale land use changes in nearly real time, it is better to use the satellite images with higher spatial resolution. Plus, land use classification accuracies in this study are problematic. The highest overall accuracy was about 71% in 2007, while in other years, they were at most 50%. Setiawan, Yoshino, & Philpot (2013) reported that over 40% of pixels from MODIS EVI data are mixed pixels that contain several land uses. The low spatial resolution of MODIS EVI dataset and temporal composite dataset of MODIS data products mainly resulted in the low land use classification accuracy (Campagnolo et al., 2016; Tan et al., 2006), although the satellites mounting MODIS sensors daily and observing the terrestrial surface and the remote sensed images are supposed to be useful to monitor temporal environmental changes of the earth. For detecting tiny land use changes over a wide extent of over several 100's km, datasets of high spatial and low temporal resolution are more suitable for analysis, although some troublesome problems remain to be solved. Actually, the answers to these problems depend on the research objectives.

4. CONCLUSION

Comprehensive land use planning based on long term monitoring of watershed is necessary in developing countries. This research selected the Brantas River watershed in eastern Java, Indonesia as a study area and analyzed land use change from 2002 to 2011 using a time sequential MODIS EVI dataset.

The results of this study were as follows: 1) during the 10 year period, forest had a tendency to increase acreage, while other land use categories, especially arable lands have decreased, 2) only 872 km^2 of land remained unchanged in this watershed during these ten years, 3) examination of a land use change matrix between 2002 and 2011 clarified many types of land conversion, 4) afforestation projects conducted by local people promoted under the policy of Perhutani Indonesia could be one of the causes of land use changes in this watershed.

Lastly, the overall accuracies of classification were not highly adequate to deal with land use change in detail. Congalton (1991) reported that over 85% to 90% of overall accuracy of land use classification was necessary to study land use change. A much higher classification accuracy to detect tiny land use changes was indispensable. The following future works are essential to obtain more detailed results on land use and land use changes in this area: a) The determination of timing of land use changes, locations and driving forces for these changes, b) Analysis of the temporally trajectories of land use change and cycles of land use which seen in rice paddy fields or in traditional shifting cultivation, c) Research on optimal watershed management policy for the sustainable watershed ecosystem.

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