MONITORING OF LAKE ECOSYSTEM PARAMETER USING LANDSAT DATA (A CASE STUDY: LAKE RAWA PENING)

Bambang Trisakti*), Nana Suwargana, and Joko Santo Cahyono
Remote Sensing Applications Center
Indonesian National Institute of Aeronautics and Space (LAPAN)
*)e-mail: btris01@yahoo.com
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Abstract. Most lakes in Indonesia have suffered (decrease in quality) caused by land conversion in the catchment area, soil erosion, and water pollution from agriculture and households. This study utilizes remote sensing data to monitor several parameters used as ecosystem status assessors in accordance with the guidelines of Lake Ecosystem Management provided by the Ministry of Environment. The monitoring was done at Lake Rawa Pening using Landsat TM/ETM+ satellite data over the period of 2000-2013. The data standardization was done for sun angle correction and also atmospheric correction by removing dark pixels using histogram adjustment method. RGB color composites (R: NIR + SWIR, G: NIR, B: NIR-RED) were used for water hyacinth identification; thus, the lake water surface area can be delineated. Further samples were collected for water hyacinth and water classification with Maximum Likelihood method. Total Suspended Matter (TSM) by Doxaran model and the water clarity from field measurement was correlated to build water clarity algorithm. The results show that Lake Rawa Pening was deterioting in term of quality during the period of 2000-2013; it can be seen from the dynamic rate of the shrinkage and the expansion of the lake water surface area, the uncontrolled distribution of water hyacinth which it covered 45% of the lake water surface area in 2013, the increased of TSM concentration, and the decreased of water clarity. Most parts of Rawa Pening's water have clarity less than 2.5 m which indicated that the thropic status is hypertrophic class.

Keywords: *lake ecosystem, Landsat, lake water surface area, TSS, water clarity*

1 INTRODUCTION

Nowadays, most of lake ecosystems in Indonesia have suffered from degradation (decrease in quality) which causes problems in water resources conservation, fresh-water supply, floods and other problems. Lake ecosystem consists of the catchment area, lake surroundings and lake waters. In general, the lake ecosystem degradations (MoE, 2012) are in the form of environmental damages and soil erosion caused by illegal deforestation in the catchment area and land management which are not in accordance with its carrying capacity, the shallowing and shrinkage of the lake that can be observed from the converting status from lake into a swamp and then into a land, water pollutions that disturb the growth of aquatic biota and lake water utilization, algae bloom caused by the lake water's nutrient enrichment due to organic wastes and fertilizer contaminations, and alterations in lake water level fluctuations caused by the damaged catchment area coupled with hydropower which disturbs the ecological balance of the lake ecosystem.

The Ministry of Environment of Indonesia has issued Guidelines for Lake Ecosystem Management which contains parameters that affect the status/quality of lake terrestrial ecosystem, lake border ecosystems and lake aquatic ecosystem.

Table 1-1: Criteria of the lake aquatic ecosystem (MoE, 2008)

Lake Parameter	**Lake Ecosystem Status**		
	Good	**Threatened**	**Damaged**
	Aquatic Ecosystem		
Thropic status	Oligotrof-Mesotrof	Eutrof	Hypertrophic
Water quality status	Uncontaminated	Moderately contaminated	Heavily contaminated
Biodiversity	Balanced trophic level (primer/secunder producers, consumers/ tersier)	Unbalanced trophic level	No trophic level
Waterplant coverage	Controlled, undistributed, does not disturb the lake function	Less controlled, disturbs the lake function	Uncontrollably spread, disturbs the lake function
Algae/ microcystis	Few	Considerable amount	Blooming
Fish cultivation's food waste	Fish production and food extraction are in accordance with lake capacity and the permit	Fish production and food extraction are not in accordance with lake capacity, but in accordance with its permit	Fish production and food extraction are not in accordance with lake capacity and its permit

Table 1-1 shows the criteria of the lake water ecosystem based on the guidelines provided by the Ministry of Environment (MoE, 2008). The change of parameter conditions can be used as an indicator, whether the condition of the catchment area and the lake are good, threatened, or damaged. Therefore, monitoring these parameters is very important to support the priority-lake management in Indonesia.

The use of satellite remote sensing data for assessing and monitoring the lake aquatic ecosystem parameters has been done by some researchers; for example, Trisakti *et al.* (2013) developed methods to determine lake water surface area and to identify water hyacinth that covered the lake water surface area of Lake Limboto, Brezonikn *et al.* (2002) conducted lake's water quality mapping (especially, chlorophyll and water clarity) in United States to determine the trophic state of lakes. Li and Li (2004) stated that monitoring could be done for various-lake sizes by using images with different spatial resolution. Even in other countries, satellite data are not only used for the purpose of research and model development, but they have been used to support the operational monitoring of lake's water quality and trophic conditions. Some researchers have developed mapping models of water quality parameters (chlorophyll, water clarity, temperature and suspended solid) and lake's trophic state using Landsat TM/ETM+, and those models have been operationally implemented to monitor the condition of some lakes in the United States and Canada (Brezonik *et al.*, 2002; Liu *et al.*, 2007; Powell *et al.*, 2008). Water trophic state indicates fertility rates for a wide variety of nutrients contained in the lake's water. The higher the level of fertility waters, the faster the algae bloom would be, which further led to the death of fish.

In Indonesia, the utilization of satellite data for lake aquatic ecosystem monitoring are almost in research level. Only few cases have been brought to operational level. This is due to the lack of standardization of data processing procedure which results in inconsistent information. Further, the generated algorithm or model will has limitation that valid only in the certain time and certain location. This study utilized remote sensing data to monitor several parameters of lake aquatic ecosystem in accordance with the guidelines of Lake Ecosystem Management provided by the Ministry of Environment. This paper is the improvement of our previous study that presented on National Seminar of Remote Sensing (Trisakti *et al.*, 2014).

2 MATERIALS AND METHODODOLOGY

The research location is Lake Rawa Pening, which is one of the 15 priority lakes listed in the lake management and rescue program over the period of 2010-2014 (MoE, 2011). The satellite data in this research was multi temporal satellite imageries, Landsat TM/ETM+ over the period of 2000-2013. The data processing was divided into three stages: data standardization, lake water surface area and water hyacinth distribution mapping, and water quality extraction (TSM and water clarity).

Landsat TM/ETM+ imageries were geometrically and radiometrically corrected to repair the position and the pixel value errors due to difference of solar lighting position and atmospheric composition (Trisakti and Nugroho, 2012). Sun correction method was conducted to eliminate the differences of pixel value of imagery caused by solar lighting position. Correction process was conducted by changing digital value of pixel into radian values (radiation from the object to the sensor), and then the radian values were changed into reflectance. Furthermore, atmospheric correction was conducted by assuming that the dark object absorbed all the energy of electromagnetic waves; thus, there is no reflection/scattering of electromagnetic waves coming from the object to the sensor. In other words, if the object's pixel in the image has certain values, then they came from atmospheric backscattering values which entered the sensor.

Some objects can be used as the dark objek such as: deep water or dark shadow due to high density cloud. In this research, the dark object was firstly identified in each imagery. If the dark object was identified then the correction was done through several step, they were: seeking minimum pixel value for each band, then the minimum value were used to reduce the pixel values of the entire imagery.

The second stage is the mapping of water surface area and water hyacinth distribution (Figure 2-1). The lake's water surface area mapping was done by identifying water hyacinth by using RGB color composite (R: NIR + SWIR, G: NIR, B: NIR-Red), where the water hyacinth was appeared white and clearly distinguishable from the another objects (vegetation and non vegetation); and then the lake water surface area was delineated (Trisakti *et al.*, 2013). Based on the field survey observation result, the thick-white color (in RGB color composite imagery) on water hyacinth refers to the good and green condition of water hyacinth which indicates enough water supply (for water hyacinth to grow on water surface or wet ground which is part of the lake). Meanwhile, the thin-white color (in RGB color composite imagery) on water hyacinth represents the less green condition because the water hyacinth does not get enough water supply (the water hyacinth grows on dried ground which is not part of the lake). The delineation of lake water surface area was done by considering the thick-white colored of the water hyacinth.

Water hyacinth distribution mapping was conducted through several steps: image cropping using lake water surface area, sample collecting from 3 classes (aquatic vegetation, water bodies, and soil) with 45 samples in total, image classification using Maximum Likelihood Enhanced Neighbor to obtain Water hyacinth distribution.

Furthermore, this study calculated the average of shrinkage and expansion of lake water surface area per year and the percentage of vegetation coverage in Lake Rawa Pening Lake by the following equation:

$$S = \frac{(A2 - A1)/A1}{n2 - n1} \times 100\ \% \qquad (2\text{-}1)$$

$$V\ (\%) = (W/A)\ X\ 100\% \qquad (2\text{-}2)$$

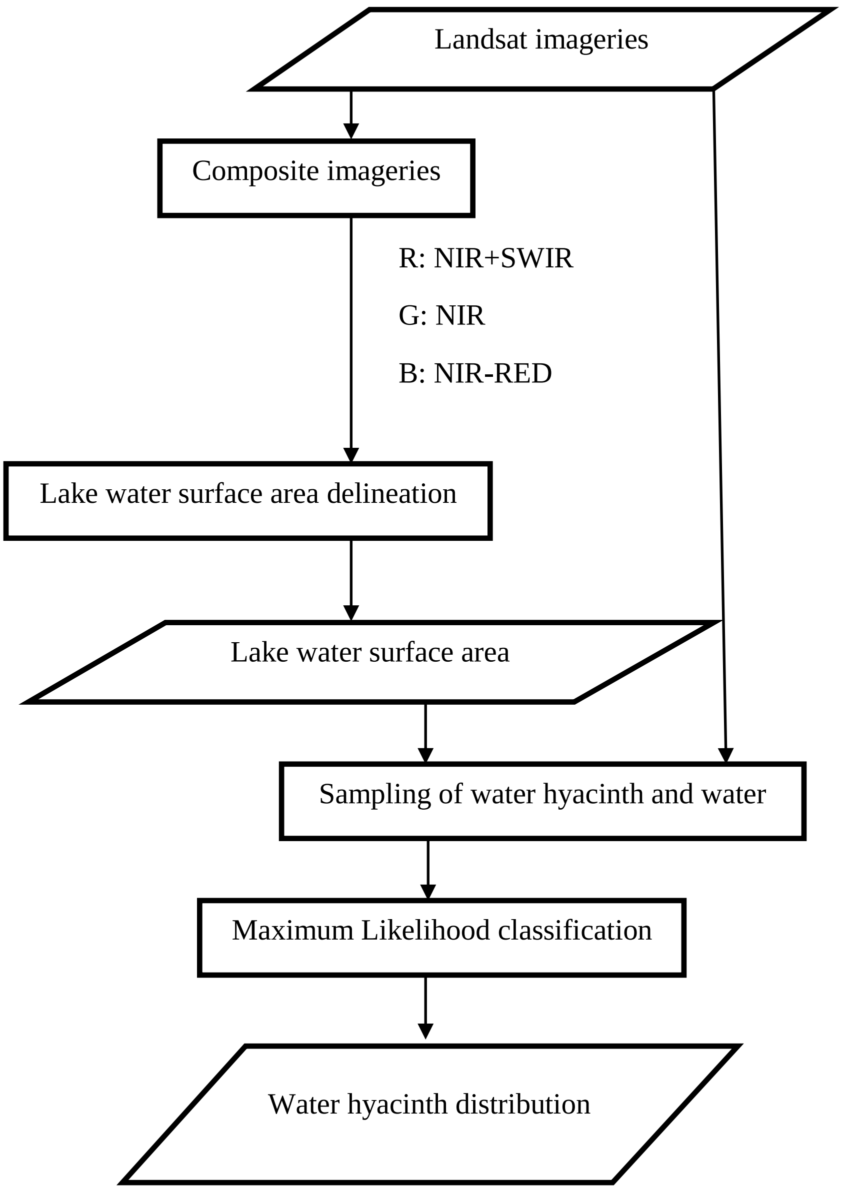


Figure 2-1: Flowchart of water surface area and water hyacinth distribution mapping

With S is the average of shrinkage (-) or expansion (+) of lake water surface area, A1 and A2 are the lake water surface area from the initial year and the final year, n1 and n2 are the initial and final year, V is vegetation coverage percentage, W is water hyacinth area and A is lake water surface area.

Water quality mapping was conducted by using TSM extraction algorithm model developed by Doxaran *et al.* (2002). Figure 2-2 shows the algorithm model by Doxaran, the correlation between TSM and NIR/ Green band ratio, this model was built based on the results of spectroradiometer measurement at various TSM concentrations (10-1000 mg/l), and has been applied to Landsat and SPOT data. Meanwhile the clarity model was developed based on the field measurement data. The measurement results of TSS and water clarity of Lake Tondano in 2012, and the measurement results of TSM and water clarity of Lake Kerinci in 2013 were combined to achieve the water clarity with TSM correlation algorithm as shown in Figure 2-3 (Trisakti *et al.*, 2013). This algorithm was used to map the water clarity of Lake Rawa Pening. Then water clarity map can be used to indicate the trophic state of lake water.

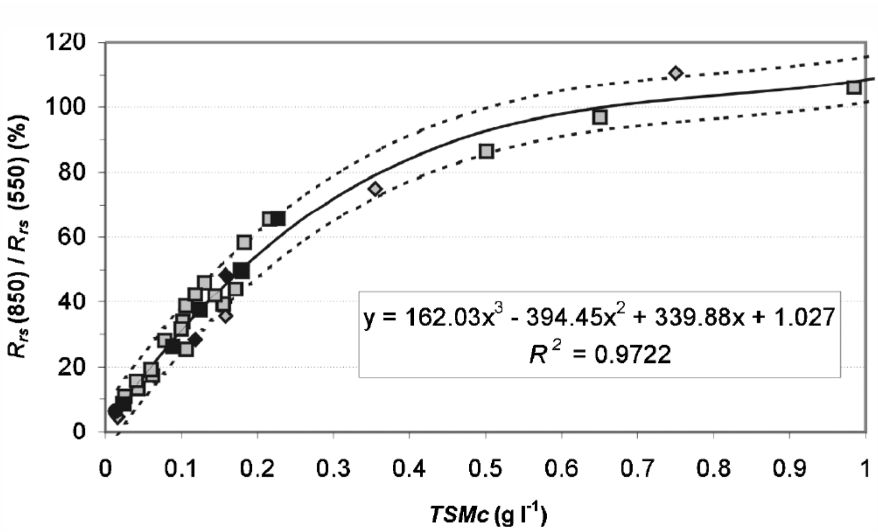


Figure 2-2: TSM algorithm developed by Doxaran *et al.* (2002)

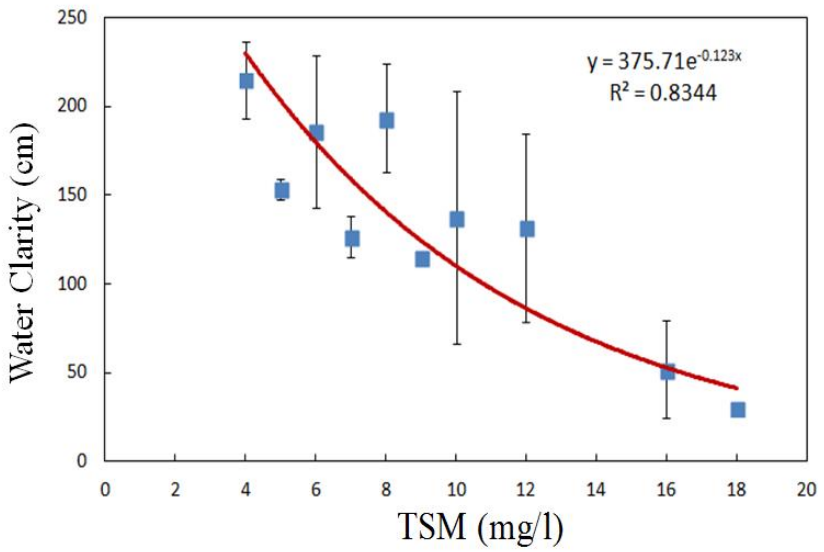


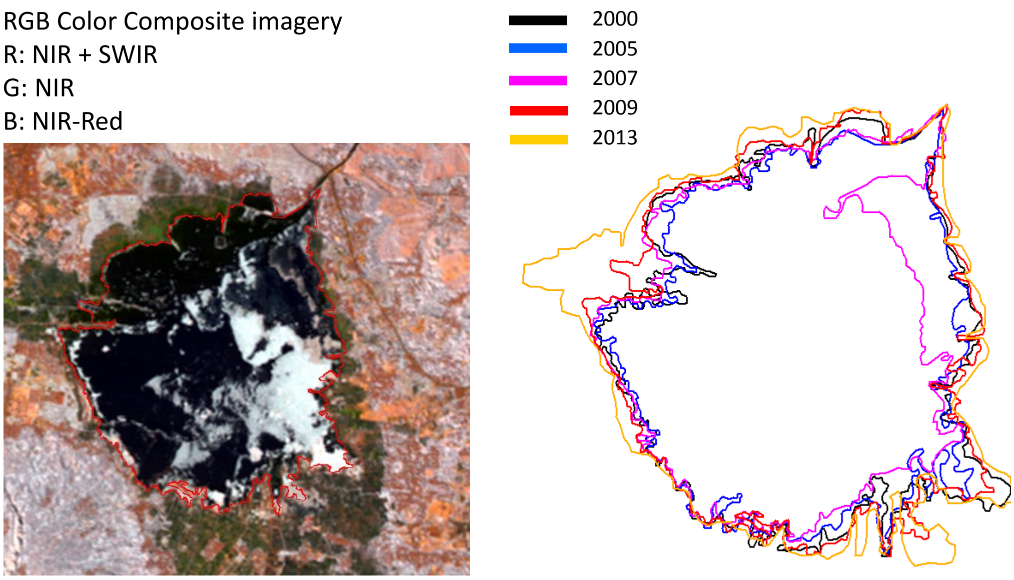
Figure 2-3: The correlation model between TSM and lake's water clarity (Trisakti *et al.*, 2013)

3 RESULTS AND DISCUSSION

Figure 3-1 shows an example of the delineation of lake water surface area of Lake Rawa Pening using RGB color composite imagery (R: NIR + SWIR, G: NIR, B: NIR-Red), and the monitoring results of lake water surface area changes of Lake Rawa Pening in period 2000 - 2013. Water hyacinth was represented by the white color. The presence of water hyacinth coverage was taken into consideration to determine lake water surface area of lake Rawa Pening. The monitoring result of lake water surface area change using multi temporal Landsat data showed that the lake's shape and area were changed every year due to the shrinkage and expansion of the lake water surface area.

The average of shrinkage and expansion per year of lake Rawa Pening are shown in Figure 3-2. Lake Rawa Pening was shrinking during the period of 2000-2007. The highest shrinkage rate per year happened in 2007 with 4.4% per year. However, over the period of 2007-2013, lake water surface area of Lake Rawa Pening expanded with expansion rate 3.5%-12.8% per year. The lake water surface area of lake Rawa Pening in 2013 was around 2.035 ha.

Water hyacinth is one of many aquatic vegetation that grows on the lake water surface (Figure 3-3). Color composites were created by selecting a combination of the highest spectral canals for water hyacinth; this selection was based on the analysis of the spectral differences from vegetation samples. Water hyacinth found in Rawa Pening has high level of green color and photosynthetic activity; thus, they have high reflections on NIR and SWIR canal, as well as low reflection on red canal. Therefore, with the color combination of RGB (R: NIR + SWIR, G: NIR, B: NIR-Red), the hyacinth's pixels will have high values on R, G and B color, which then form a joint white color.



a. Delineation of lake water surface area with RGB color composite imagery

b. Lake water surface area change in period 2000-2013

Figure 3-1: The mapping result of lake water surface area changes in the period of 2000-2012

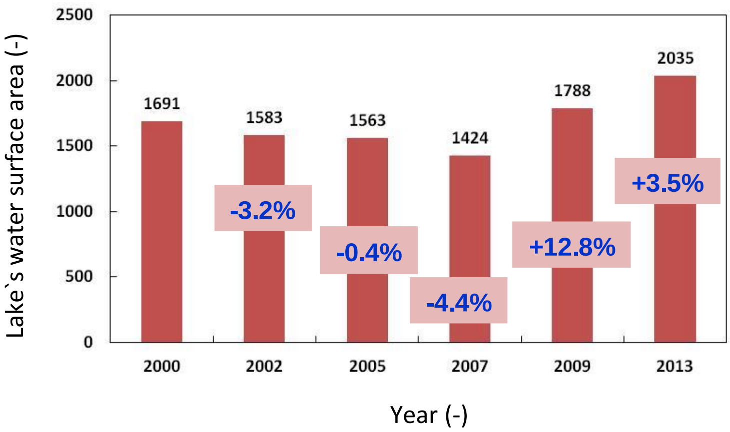


Figure 3-2: Lake water surface area change in period of 2000-2013, negative (-) is the shrinkage rate and positive (+) is the expansion rate

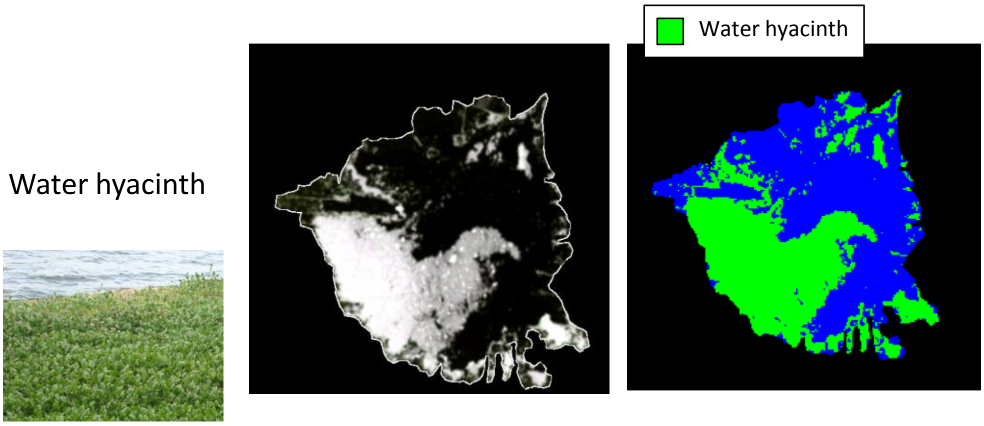


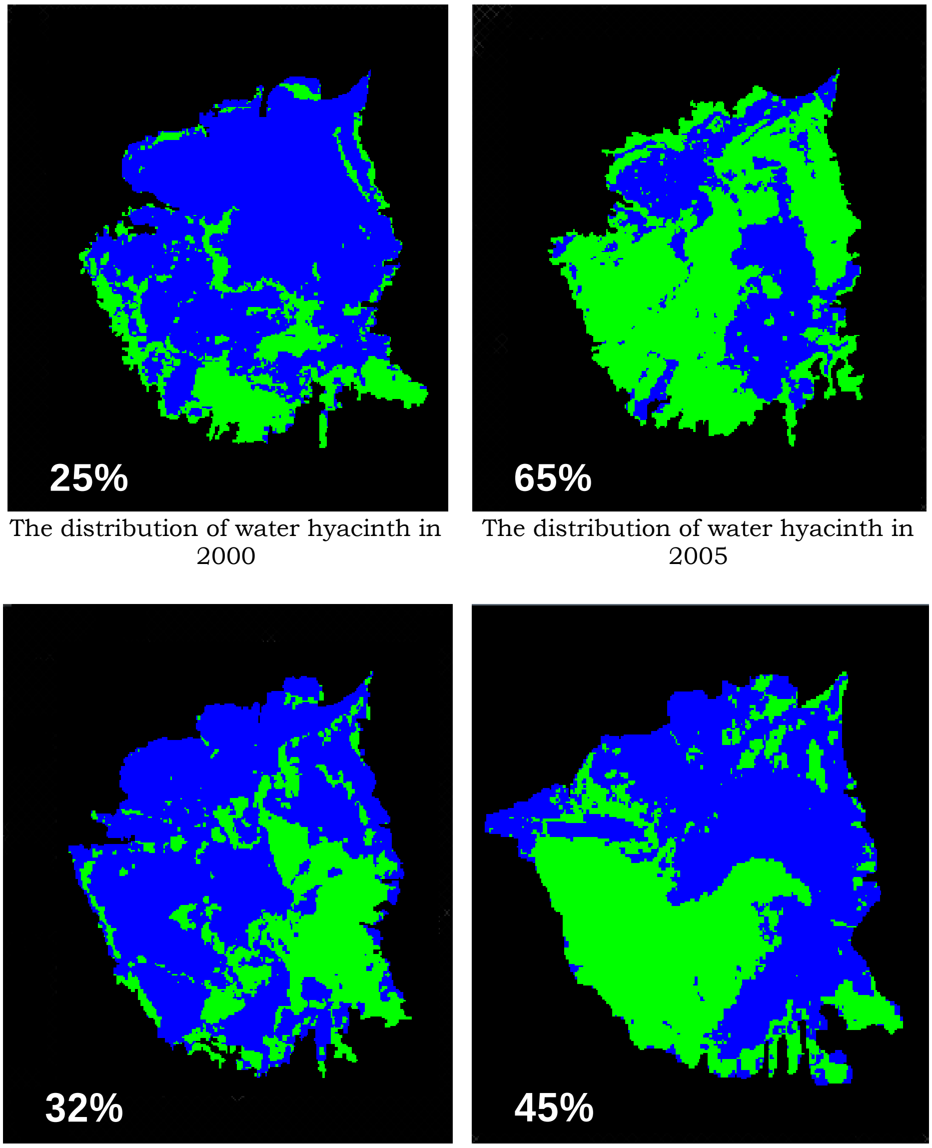
Figure 3-3: The appearance of water hyacinth and classification result of it in 2013

The spatial information of water hyacinth distribution was obtained by digital classification with Maximum Likelihood Enhanced Neighbor method. Hyacinth's distribution classification results in 2013 are shown on Figure 3-3, the classification of water hyacinth was successfully and accurately classified (accuracy >95%).

Figure 3-4 shows the distribution of water hyacinth in Lake Rawa Pening over the period of 2000-2013. White letters on the left-bottom shows the percentage of the area which was covered by water hyacinth (vegetation covered area). Water hyacinth's growth fluctuated during the period of 2000-2013, the water hyacinth's growth occurred significantly in 2005 and 2013. In 2000, hyacinth's coverage reached 25%, the percentage increased up to 65% in 2005, then declined to 32% in 2009, and in 2013 hyacinth's coverage reached the number of 45%. The rapid growth of water hyacinth would disturb the fish cultivation activity. Some lakes in Indonesia such as Lake Limboto and Tempe have rapid hyacinth's growth. Its rapid growth makes water hyacinth the main problem to be solved quickly.

Water hyacinth's coverage area in Lake Rawa Pening was very high, according to the survey conducted in November 2007 and February 2008 by (Soeprobowati and Suedy, 2010), it was reported that the percentage of water hyacinth's coverage area in November 2007 and February 2008 were around 60%. Furthermore, based on information from the local government, the program to clean out water hyacinth had been conducted. These reports are in line with this research result; in 2005 (before 2009) water hyacinth's coverage was around 65%, and then decreased to 32% in 2009.

Based on the Lake Ecosystem Management Guidelines, the uncontrolled spreading of water hyacinth to the point of disturbing lake's function, indicates that the lake's status was in damaged condition. The analysis shows that the growth of water hyacinth in Rawa Pening was uncontrolled, they spread throughout all the lake water surface and disturb the lake's function and community's activities.



The distribution of water hyacinth in 2000

The distribution of water hyacinth in 2005

The distribution of water hyacinth in 2009

The distribution of water hyacinth in 2013

Figure 3-4: Water hyacinth distribution monitoring in Lake Rawa Pening over period 2000-2013

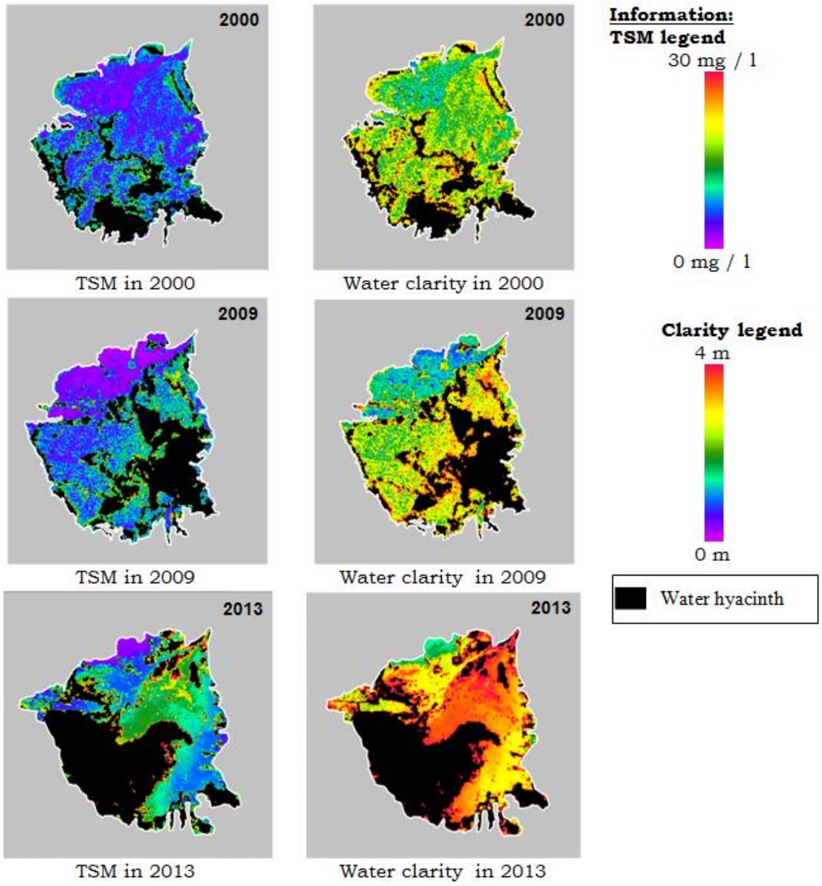


Figure 3-5: TSM and water clarity distribution of Lake Rawa Pening in 2000, 2009 and 2013

Table 3-1: Lake trophic state category based on UNEP-ILEC method (MoE, 2009)

Trophic State	Average Value			
	N Total, (mg/ L)	**P Total, (mg/ L)**	**Chlorophyll-a, (ug/ L)**	**Clarity (m)**
Oligotrophic	≤ 650	< 10	< 2	> 10
Mesotrophic	≤ 750	<30	< 5	> 4
Eutrophic	≤ 1900	< 100	< 15	≥ 2,5
Hypertrophic	> 1900	> 100	> 200	< 2,5

Figure 3-5 shows the distribution of TSM and water clarity of Lake Rawa Pening in 2000, 2009 and 2013. The black color is the distribution of water hyacinth. Distribution of TSM in 2000 was less than 15 mg/l, but the TSM concentrations increased to 20 mg/l in 2009, and it increased again up to 30 mg/l in 2013. The high concentration of TSM in 2013 spread over the central part of Lake Rawa Pening.

The water clarity pattern was inversely related to the pattern of TSM. The water clarity of the top part of the lake was quite high (>3m) with low TSM concentration levels, while the rest of the lake has low water clarity (<2m), especially the central and eastern parts of the lake that had a high TSM. In general, the water clarity in 2000 had value ranges from 1 to 3 meters; however, as time goes by, the water clarity of Rawa Pening started to wane. In 2013, Rawa Pening had water clarity less than 2m at most parts of the lake. Based on the Lake Ecosystem Management Guidelines as shown in

Table 1-1 and Table 3-1, a lake was categorized as damaged when the lake was in hypertrophic state with water clarity less than 2.5 meters. The water clarity taken from satellite image indicated that most parts of Lake Rawa Pening were in hypertrophic state.

The water clarity level of Lake Rawa Pening provided by this study was similar with the water clarity level reported by (Soeprobowati and Suedy, 2010); the ranges of water clarity are less than 2 meters, and it was also reported by (Zulfia and Aisha, 2013) that the water clarity ranges from 0.85 -1.12 m.

4 CONCLUSION

The multi-temporal-satellite-remote-sensing data have been utilized to monitor the aquatic ecosystem parameter of Lake Rawa Pening in accordance with the Lake Ecosystem Management Guidelines provided by the Ministry of Environment. Some conclusions drawn from the study are as follows:

- Lake Rawa Pening was deteriorating in term of its quality over the period of 2000-2013, which was shown from the dynamic shrinkage and expansion rate of its surface, the uncontrolled growth of water hyacinth which covers 45% of the lake’s water level.
- The increased TSM concentration and the decreased water clarity were occured in period 2000-2013. Most parts of Lake Rawa Pening had water clarity less than 2.5 m which indicated hypertrophic state.
- The percentage of water hyacinth’s coverage and the water clarity obtained by this study are relatively similar to previous publication.

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