ENVIRONMENTAL QUALITY CHANGES OF SINGKARAK WATER CATCHMENT AREA USING REMOTE SENSING DATA

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Abstract. Lake Singkarak in west Sumatera is currently in very poor condition and become one of the priorities in the government lake rescue program. High sedimentation rate from soil erosion has caused siltation, decreasing of quality and quantity of lake water. Monitoring of the environment quality changes of the lake and its surrounding are required. This study used Landsat and SPOT satellite data in periods of 2000-2011 to evaluate environmental quality parameters of the lake such as land cover, lake water quality (total suspended solid), water run-off, and water discharge in Singkarak lake catchment area. Maximum likelihood classifier was used to obtain land cover. Total suspended solid was extracted using Doxaran algorithm. The look up table and rational method were used to estimate run-off and water discharge. The results showed that the decreasing of forest area and the increasing of settlement were consistent with the increasing of average run-off and water discharge in Paninggahan and Sumpur sub-catchment area. The results were also consistent with the increasing of TSS in Singkarak lake, where TSS increased from around 2-3 mg/l up to 5-6 mg/l in the periods of 2000-2011.

Keywords: *Singkarak lake, total suspended solid, run off, water discharge, Landsat, SPOT*

1 INTRODUCTION

In general, catchment area degradations in Indonesia are mainly caused by the conversion of forest land to agriculture or to other land uses (residential, industrial, and mining). Conversions/land clearing which does not follow the principle of environmental sustainability can lead to many negative things, not only in its opening stages but also on the use and management phases. Land clearing on a large scale using heavy equipments may cause heavy pollution and give negative impact to the surrounding environment. Furthermore, delay planting on a cleared land will cause soil erosion during the rainy season, especially in areas with steep slopes. The high erosion in catchment areas will increase the water turbidity, which will disturb the aquatic life (rivers, reservoirs, lakes, etc.) in the upper catchment area. Therefore, it is necessary to do prevention efforts to stop the continuity of catchment area degradation, and efforts to improve the quality of the lake so that these lakes can become sustainable and can be used by the surrounding society.

According to the Environment Agency for Development and Research, there are 15 lakes that have most priority and require the follow-up action by the government for it's improvement (KLH, 2011). Lake Singkarak in West Sumatra is one of the lakes that is currently in very poor condition and becomes one of the government's priority. Problems occurred in Lake Singkarak is that the its surrounding land has low capability to store water, so water run-off and water discharge in the lake catchment area increases year by year (KLH, 2012)

Development of remote sensing techniques for monitoring water quality was began in the early 1970s. These early techniques measured spectral and thermal differences in emitted energy from water surfaces. Generally, empirical relationships between spectral properties and water quality parameters were established. Ritchie *et al*. (1974) developed an empirical approach to estimate suspended sediments, where the general forms of these empirical equations are $Y = A + BX$ or $Y=AB^X$. Y is the remote sensing measurement (i.e., radiance, reflectance, energy), and X is the water quality parameter of interest (i.e., suspended solid, chlorophyll). A and B are empirically derived factors. Total suspended solid (TSS) is one of important water quality parameters, that has been studied by many scientists. Doxaran *et al*. (2002) developed TSS algorithm from the correlation between TSS concentration and spectral measurement using spectroradiometer, and this algorithm could be applied using Landsat and SPOT data. Brezonik *et al*. (2002) dan Powell *et al*. (2008) developed chlorophyll, water transparency, and TSS algorithm models and applied the model operationally to monitoring some lakes in America and Canada. Study about watershed management have been carried out by many researchers, such as: mapping of critical land in watershed area (Prawira *et al.*, 2005), run-off coeficient and water charge estimation in catchment area (Suroso and Susanto (2006); Pratisto and Danoedoro (2008)).

Based on those studies, monitoring and evaluation of the environment quality changes in Singkarak catchment area can be done using remote sensing technique. This study was conducted to evaluate the changes of environment quality (land cover, total suspended solid, run-off, and water discharge) based on multi temporal satellite image in Singkarak lake catchment area. The information obtained by satellite data are important for planning and managing regional development, especially for supporting lake rescue program.

2 MATERIALS AND METHODS

Study area is located in Singkarak lake where catchment area is divided into 4 sub-catchment area (Sumpur, Paninggahan, Danau Singkarak and Sumani) (Figure 1). This research focus on Sumpur and Paninggahan sub-catchment areas. Multi temporal SPOT-4 and Landsat ETM+ were used as main data in this study area, and those data covered whole Singkarak catchment area. Space shuttle Topography Mission (SRTM) data was used for generating boundary of lake catchment area and sub catchment area, slope, and other parameters such as height difference and river length. Tropical Rainfall Measurement Mission (TRMM) satellite data was used to produce rainfall that used as input to calculate rainfall intensity. Other secondary data, such as Administration maps, climate data/map and soil type maps, were collected and used to support run-off and water discharge estimation. Landsat ETM+ and SPOT-4 data were obtained from National Institute of Aeronautics and Space (LAPAN) with acquisition date July 15th 2000 and May 11st 2011 respectively.

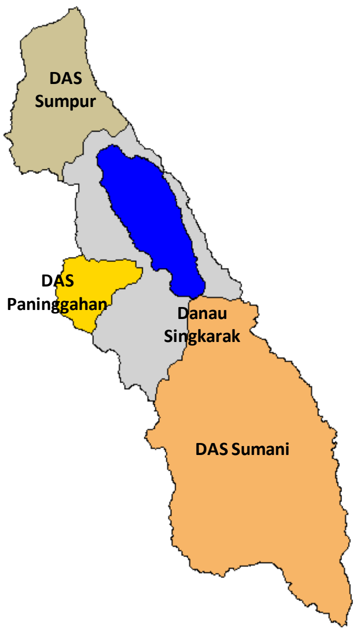


Figure 1. Study area of Singkarak Lake catchment area

Research procedure is shown in Figure 2. Data correction were conducted to prepare standard data. The procedure of data correction reported by Trisakti and Nugroho (2012) was used to correct Landsat and SPOT-4 data from the geometric and radiometric error. The data were cropped by the catchment boundary generated from SRTM data, and then maximum likelihood classifier method was applied to produce land cover map. The classification result was then verified and corrected by using ground truth data and secondary data that obtained from local government offices.

Run-off and water discharge were estimated using some parameters extracted from satellite data and other reference data. Detail methods for estimation run-off and water discharge were explain and reported in the previous publication (Trisakti *et al.*, 2013). Parameters used for run-off coefficient estimation were soil type, land cover, and slope. Run-off coefficient (C) from each parameters was determined using look-up table method, then the average run-off coefficient in catchment area was calculated using Equation 1. On the other hand, parameters used for water discharge are run-off coefficient, catchment area, maximum and minimum height difference in the catchment area, river length and rainfall intensity as shown in Equation 2.

$$C_{average}=(C_{land\ cover}+C_{slope}+C_{soil\ type})/3 \quad .... \quad (1)$$

$$Q = 0.278\ I\ C_{average}\ A \ \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where, Q is water discharge (m^3/s), I is rainfall intensity (mm/hour), A is area (m^2) and C is run-off coefficient.

Total suspended solid (TSS) was calculated using equation published by Doxaran *et al.* (2002), the equation was developed from the correlation between TSS concentration and spectral measurement using spectroradiometer equipment. The equation is shown in Figure 3. Finally, change analysis was conducted by doing comparison between the results (land cover, run-off, water discharge and TSS) in 2000 and the results in 2011.

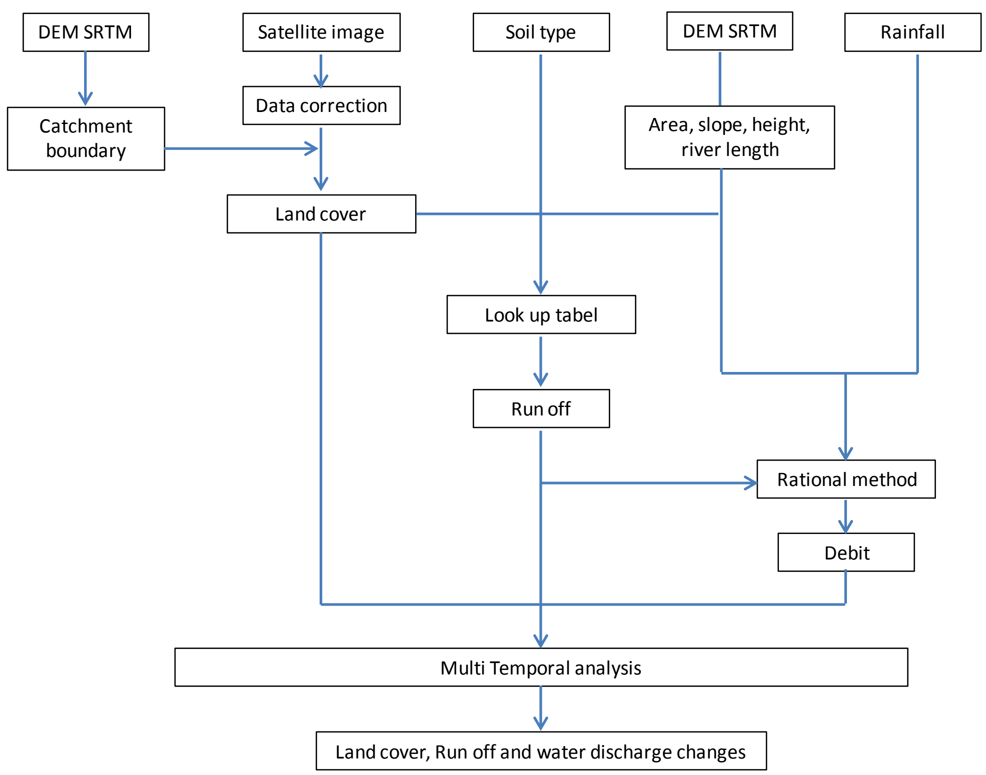


Figure 2. Flowchart of research procedure

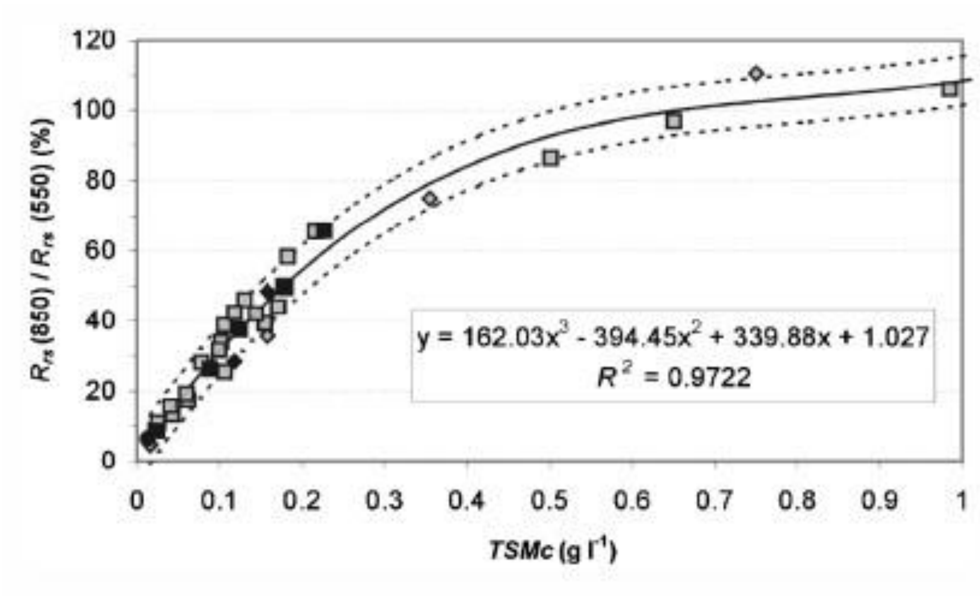


Figure 3. TSS Algorithm developed by Doxaran (2002).

3 RESULTS AND DISCUSSION

3.1 Mapping land cover change in Singkarak catchment area

Land cover classification in 2000 and 2011 were conducted using maximum likelihood classifier. The classification results were then evaluated and corrected using ground truth data and secondary data from local government offices to improve the accuracy of land cover of the study area. The land cover result in 2000 and 2001 are shown in Figure 3. The statistic value of land cover area in 2000 and 2001 for Sumpur and Paninggahan sub catchment inside Singkarak catchment area are shown in Table 1. From the result, it showed that there were an increasing of settlement area and decreasing of forest area significantly, where settlement area in 2011 increased 10 times comparing to settlement area in 2000. The changes of forest and settlement area were considered to increase run-off and water discharge in Sumpur and Paninggahan sub-catchment areas.

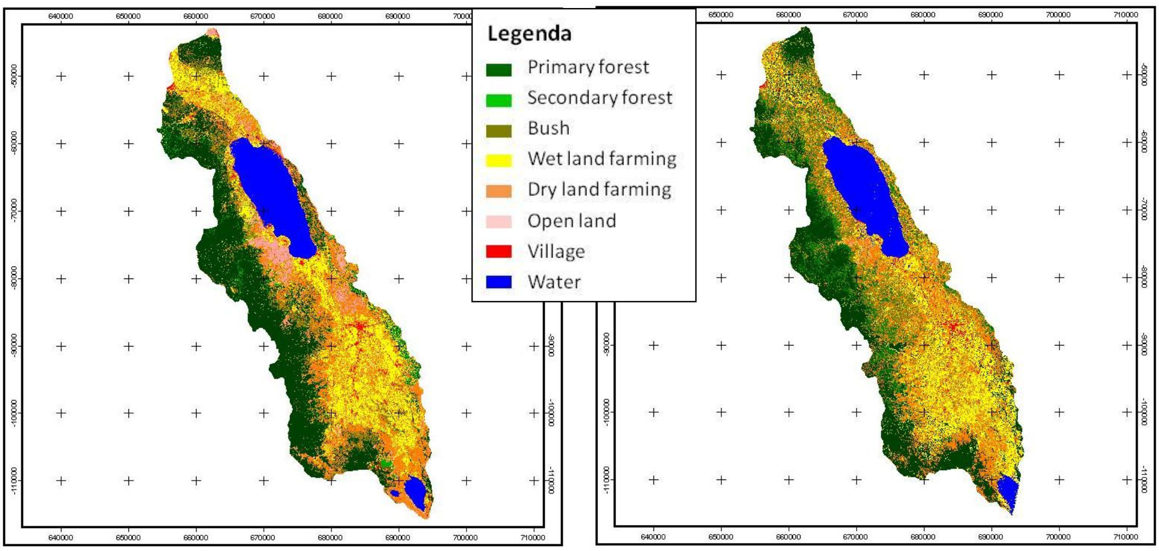
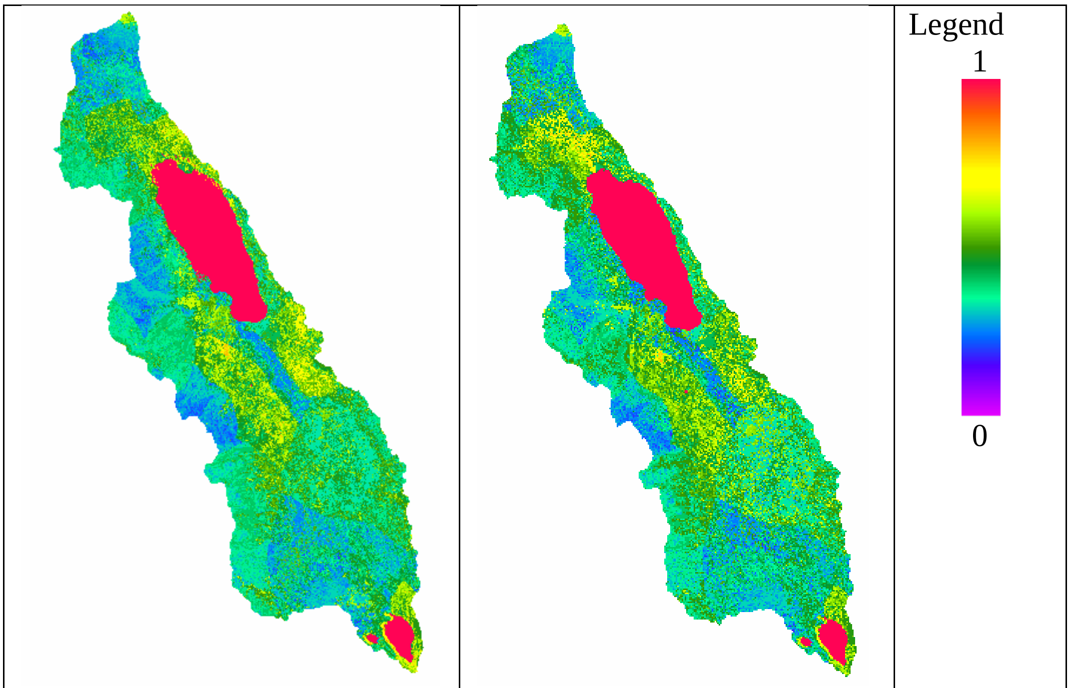


Figure 3. Land cover result in Singkarak Lake catchment area.

Table 1. The comparison results of each land cover wide area in Sumpur and Paninggahan sub-catchment areas in 2000 (left) and 2011 (right)

District	Sumpur (ha)		Paninggahan (ha)	
	Year 2000	Year 2011	Year 2000	Year 2011
Dry Agriculture	375.75	496.4	1644.39	3146.36
Open Land	290.61	156.4	3108.78	2253.56
Forest	4576.59	3590.92	6896.52	5937.28
Settlement	105.84	1152.72	348.57	2643.16
Agriculture	3.69	4.08	403.38	394.24
Shrubs	168.66	118.88	3761.28	1787.28



(a) Run-off coefficient in 2000 (b) Run-off coefficient in 2011

Figure 3. Run-off coefficient in Singkarak Lake catchment area in 2000 and 2011.

3.2 Run-off and water discharge estimation

Distribution of run off coefficient in Sumpur and Paninggahan sub-catchment area were estimated based on land cover generated from the satellite data, slope and soil types obtained from soil map. Figure 5 shows distribution of run-off coefficient in Singkarak Lake catchment area in 2000 and 2011. From the visual observation of Figure 5, the distribution values of run-off coefficient in 2011 was little higher than the distribution values in 2000.

Average run-off coefficients were calculated for both Sumpur and Paninggahan sub-catchment area to know the change trend of run-off coefficient in periods 2000-2011. Water discharge areas were also calculated based on the run-off coefficient, sub-catchment area and rainfall intensity in both sub-catchment area. Table 2 shows the average run-off coefficient and water discharge in Sumpur and Paninggahan sub-catchment area in 2000 and 2011. Average run-off coefficient and water discharge of both sub-catchment areas increased. The increasing of average run-off coefficient and water discharge in Sumpur sub-catchment area were higher comparing to those results in Paninggahan sub-catchment area.

3.3 Mapping TSS change

The changes of land cover, run-off and water discharge in the Singkarak Lake catchment area caused deterioration of water quality in Singkarak Lake. Remote sensing technique offers the possibility to predictions the water quality through the wavelength-sensitive to the particles suspended in the water column. Figure 4 shows the results of TSS distribution in Singkarak Lake for 2000 and 2011 using the algorithm developed by Doxaran *et al*. (2002). The figure shows that the content of suspended particle in water column (TSS) of Singkarak lake increased, from around 2-3 mg/l in 2000 up to 5-6 mg/l in 2011.

According to the all results mentioned before, land cover changes in Sumpur and Paninggahan sub catchment area were considered with close relationship with the increasing or decreasing run-off coefficient, water discharge and TSS concentration.

Table 2. Comparison results of run-off coefficient and water discharge at Sumpur and Paninggahan sub catchment area in 2000 and 2001

Sub Catchment	Average run-off coefficient, 2000	Average run-off coefficient, 2011	Discharges (m^3/s), 2000	Discharges (m^3/s), 2011
Sumpur	0,40	0,43	887	957
Paninggahan	0,34	0,35	238	239

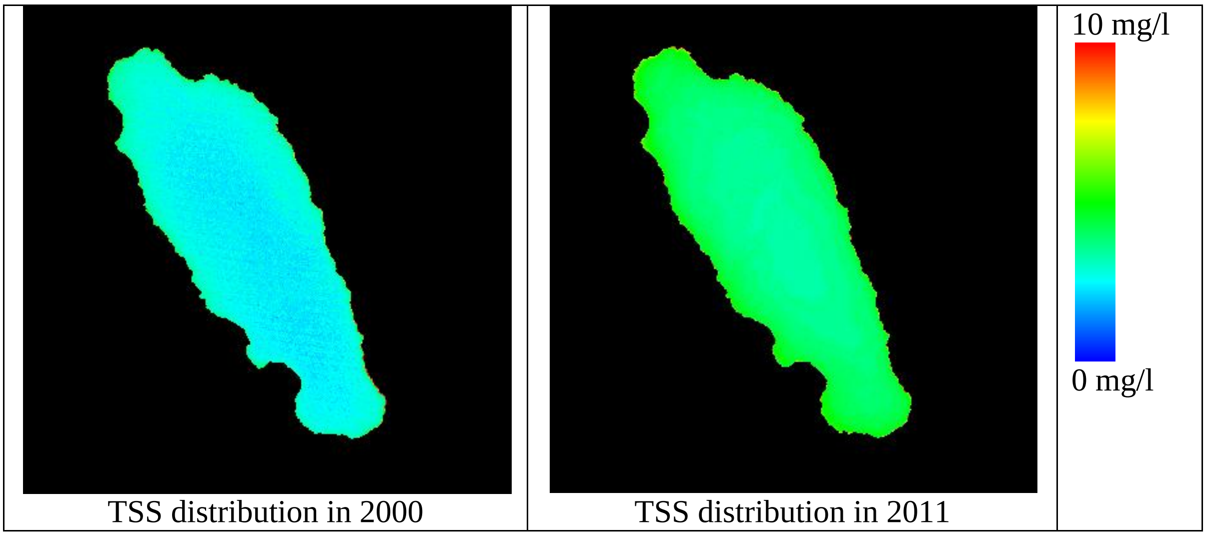


Figure 4. TSS distribution in Singkarak Lake in 2000 and 2011.

4 CONCLUSION

Environmental quality (land cover, total suspended solid, run-off and water discharge) changes can be evaluated using remote sensing data. The decreasing of forest area and the increasing settlement in the periods of 2000-2011 in Paninggahan and Sumpur sub-catchment area were considered with good consistency with the increasing of average run-off and water discharge. The results had also good consistency with the increasing of TSS (water turbidity by suspended solid) in Singkarak Lake from from around 2-3 mg/l up to 5-6 mg/l in the same periods. This information obtained by satellite data were very important data for planning and managing regional development, especially for supporting lake rescue program

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