Remote Sensing and GIS Application for Sedimentation Modeling in Porong River Estuary as an Impact of Lapindo Mudflow, Sidoarjo

A P Firdausy[*] **and Sudaryatno**

Cartography and Remote Sensing, Faculty of Geography, Universitas Gadjah Mada Sekip Utara, Bulaksumur, Yogyakarta 55281

andikaputrif@gmail.com

Abstract. Lapindo mudflow that has occurred since May 2006 in Porong, Sidoarjo have raised thorny issue. One of the consequences that turned up physically was the alteration that has occurred in Porong River estuary. Porong River estuary has undergone drastic morphological change since 2006 to 2016 that became interesting phenomenon studied using remote sensing imagery. Landsat 7 ETM+ and Landsat 8 OLI/TIRS images were used to observe the changes that occurred in Porong River estuary. Porong River estuary had additional land area of 149.4 Ha in 2000-2006, 93.79 Ha in 2006-2010 and 100.24 Ha in 2010-2016. This addition was largely due to the change of land use in the sub-watershed, input from Lapindo mudflow, as well as human activities in the development of a new delta called Sarinah Island. There were several algorithms that were used in the calculation of the sediment concentration value (SSC), such as blue, green, near infrared band, also Doxaran, NDSSI, and the red/near infrared band ratio. However, the SSC of pixel value did not have strong correlation with the SSC field value. The dynamic of object and accuracy of the algorithm became the most influential factor that must be considered in calculating the value of SSC.

Keywords*: Sediment, Estuary, Porong River, Landsat, Lapindo

1. Introduction

Sedimentation is a process that definitely occurs in every watershed. Sedimentation occurs because of the precipitate of erosion materials and material transport from previous processes from upstream to downstream of a watershed. The disaster was caused by PT Minarak Lapindo Jaya drilling resulted in a burst of hot mud that spurted up to now. This disaster has occurred for more than ten years since 26 May 2006 around Porong Sub- district, Sidoarjo Regency, East Java. As a result of this disaster, the surrounding area was drowned by continuous mud out of the earth.

The modeling of Lapindo mudflow has been done just after the first overflowed [1]. However, the dynamics of bursts that were constantly changing over time required continuously updated modeling as the mudflows addition, also the morphological and ecological changes of the estuary. The development of modeling was done to observe the sediment growing pattern as input in the downstream planning of the watershed as the reference for the future cases.

Monitoring the type, quantity, and spatial distribution of sedimentary minerals is crucial. Sediments might affect water quality and suitability for drinking water, tourism, and industrial purposes. Suspended sediment might block the transmission of solar radiation and reduce the photosynthesis of underwater vegetation and underlying phytoplankton. In fact, underwater vegetation and phytoplankton play a huge role in the food chain of aquatic ecosystems.

Research on sedimentation using Landsat 8 OLI/TIRS imagery combined with GIS-based modeling has not been done in Indonesia, especially which located in Porong River estuary. In addition, the influence of sediment input from outside the watershed will be interesting object to be studied, in this case a flow of overflow of Lapindo mud sedimentation.

The aim of this research is to find out the distribution and sediment concentration in Porong River estuary before and after Lapindo mudflow with Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIRS. This study also aims to model changes in the pattern of sediment distribution in the estuary of Porong River in the period of 2000-2016 by using geographic information system.

2. Research Method

Landsat images were processed by performing geometric, radiometric, and atmospheric correction. Image to image geometric correction has been done image between one image and another image. Dark Object Substract method or adjusting the histogram has been done for atmospheric correction.

The corrected image has been chosen as the sampling basis for the fieldwork. Samples of estuary water which contain sediment were taken by transect method. Thus, it has been laboratory tested to determine the value of sediment concentration (SSC) in mg/l.

The laboratory result of SSC value were correlation and regression tested with image pixel value, resulted regression coefficient. These values were chosen as the benchmark for obtaining SSC values in other images in various years. Meanwhile, images from year 2000, 2006, and 2010 had been inter-band calibrated first before applying to calculate value of SSC. The development of Porong River estuary has been spatially mapped by overlaying the images based on the years required, such as images 2000 and 2006, 2006-2010, and 2010-2016.
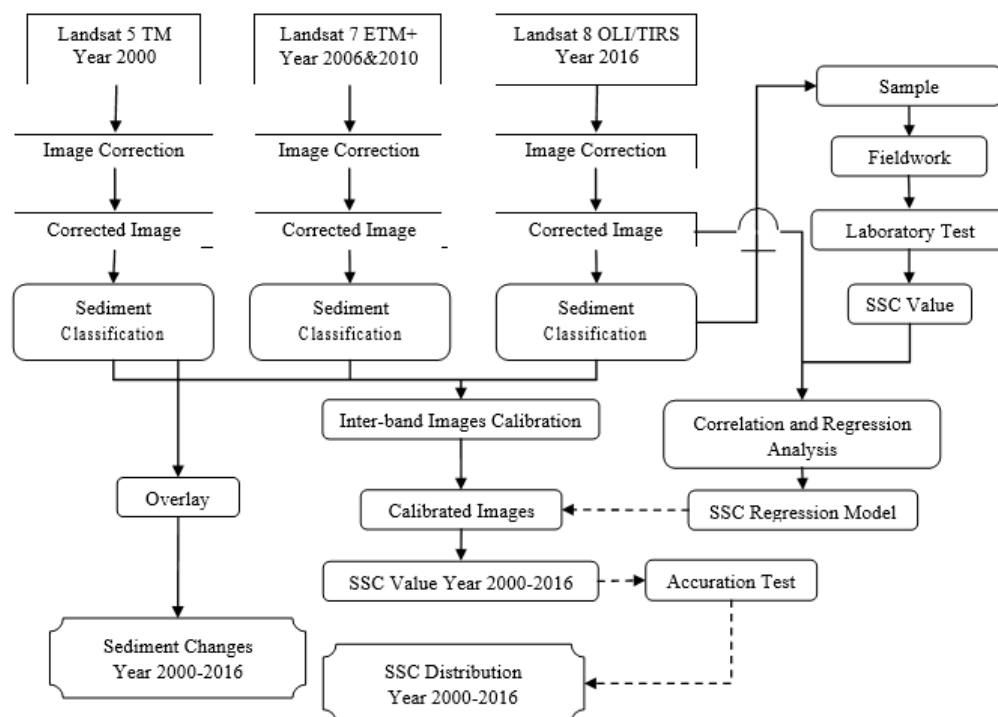
Figure 1. Flowchart of Method

3. Results and Discussion

Based on the results of field data retrieval, SSC values have been correlation and regression tested with the band values of the image. Correlation test has been used to find out the relationship between image pixel in each band and field SSC values. Several bands which have been used were blue, green, red, near infrared, and middle infrared. Meanwhile, band 1 in Landsat 8 or band blue stretching cannot be used because it would not be applied to Landsat images 5 and 7.

Based on the correlation test, it is known that each band has a relatively low correlation with the SSC value. The correlation reference is adjusted to the value of R (product moment) according to the number of samples. Thirty eight samples have been used in 5%　significance resulted 0.320 for R value. The correlation degree has not been complied, so the band which has highest correlation degree was selected as the reference? Thus, it caused by the dynamic characteristic of sediment which has higher probability in both spectral and spatial biases. In addition, image spatial resolution can also affect the accuracy of research results.

Multitemporal images within spatial researches require inter-band calibration to align the spectral standard of image pixels. Thus, at different times, the same spectral response might have different recording objects, due to the different quality of satellites and recording conditions. Images calibration has been applied to tackle that problem.

Reference in calibration between image bands has been selected from one image that is considered to have appropriate resolution and is able to represent another image. Landsat 8 image has been used as a reference to calibrate the other images. This image has been chosen not because of the latest recording time, but it has been considered to choose the best spectral value among other images. In contrast, Landsat 7 image has a gap at its spectral value due to the offline of scan line corrector so as to interrupt the calibration process. Likewise with Landsat 5 image which has an inadequate spectral display and tends to blur.

The result of that calibration is applied to algorithms that have been built to obtain SSC values. The SSC value would represent the SSC value in the same location as the sample point at different times and images. The results of the best SSC values will be the basis for mapping the SSC values in the general assessment location during the appropriate recording year.

Based on the SSC values of the six algorithms, a correlation test has been applied between SSC pixel and SSC field to determine the strongest correlation. The strongest correlation algorithm is considered to represent the SSC value for mapping the SSC value classification. The correlation coefficient value of band 1 (blue) is 0.301895. The correlation coefficient value of band 2 (green) is 0.330227. The correlation coefficient value of band 4 (near infrared) is 0.04621. The correlation coefficient value of Doxaran band ratio is 0.093752. The correlation coefficient value of NDSSI band ratio is 0.060975. While the correlation coefficient of RIR band ratio is 0.086868. The coefficient value on green band is highest and more than R (n = 38) is 0.320. So by 2016, the algorithm of the green band is considered to be the most representative of SSC values. As for band ratio, Doxaran ratio has the highest coefficient value among others.

The results of SSC value algorithm implementation can be observed by several patterns. In contrast to the SSC value of 2016, the SSC value of 2000 on band 1 (blue) and band 2 (green) have the same characteristics, which are negative. This suggests that the algorithm did not succeed in building SSC values in 2000 because SSC is unlikely to be negative. In the other hand, SSC values based on band 4, Doxaran, NDSSI, and RIR ratios show a positive value. Although it is not definitely show the right value, but these four values are still appropriate if the value of SSC.

In general, the SSC value of field results has more varied distribution rather than the result of SSC logarithm. Thus, it could be happen because the SSC value of the algorithm result is mathematical so that the resulting value is not far from the normal regression line that had been formed. In contrast, the SSC value of field results is highly dynamic. Both have different angles of view so that high correlation and determination coefficients cannot always be found easily. Differences in the range of SSC values resulted in the analysis of the increase or decrease of SSC in each period cannot take place optimally.

The dynamics or changes in sedimentary patterns on the coast are a natural phenomenon occurring in an estuary or delta, including those occurring in the Porong River estuary. This change can occur due to several factors, such as the presence of sedimentary input from the river, the fluctuation of tidal and wave energy, and the presence of human influences. In certain circumstances, human activity may be the largest and fastest factor affecting the dynamics of the estuary or delta.

The dynamics of the estuary of Porong River are observed in three periods: 2000-2006, 2006-2010, and 2010-2016. In general, the changes that occur are the growing of coastal lines. Although there are some locations that suffered coastline retreat but the extent is not prominent. This change is natural and can happen anywhere. However, the presence of large additional sediment inputs from the Lapindo bursts since 2006 may have influenced the changes.

The change of estuary area of 2000-2006 was dominated by the change of territorial waters to the mainland in 2006, which was 1,494,364,624 m2 or equal to 149,4 Ha, as represented in Figure 2. This change is a considerable amount in coastal dynamics. This may be due to several factors such as significant land-use change and may also be derived from the influence of sediment input from the Lapindo mud since May 2006.
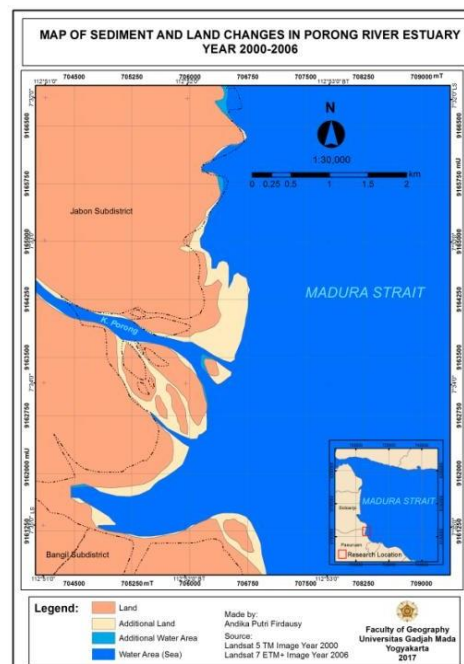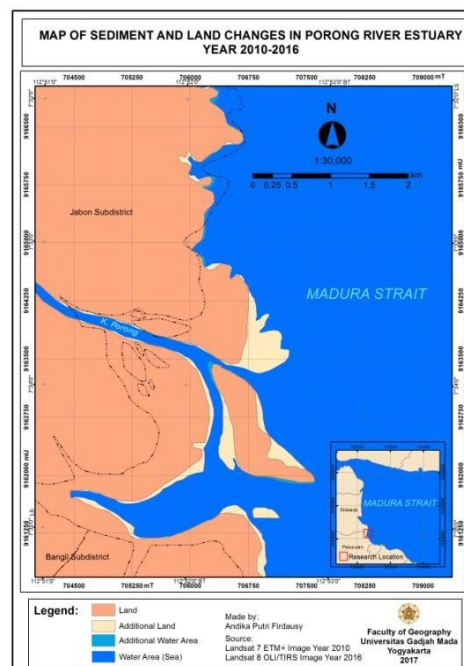

Figure 2. Map of Sediment and Land Changes Year 2000-2006

Changes in the area of estuary in 2006-2010 are more common in the newly formed delta or commonly called "Pulau Sarinah", as represented in Figure 3. The new area formed in the delta reaches tens of hectares. In addition to the influence of Lapindo mud input that flowed towards Kali Porong, the delta has undergone many changes due to efforts by the government to develop Sarinah Island. The delta area due to sediment deposition is increasing with the influence of human activity in it.
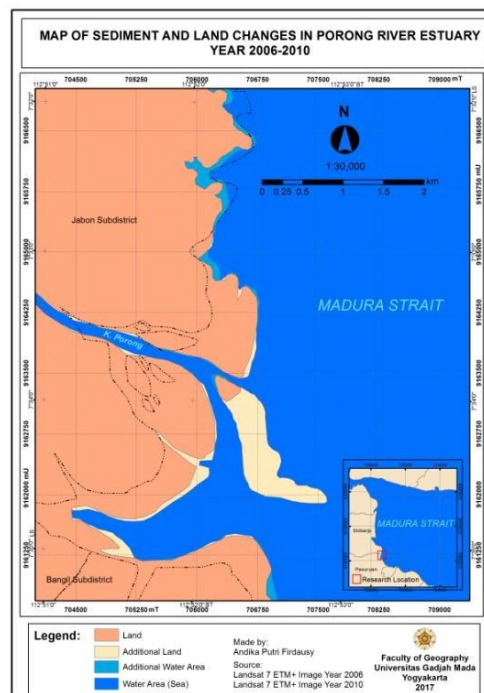
Figure 3. Map of Sediment and Land Changes Year 2006-2010

Changes in the Porong River estuary in 2010-2016 have increased again after in 2006-2010 is relatively lower than the year 2000-2006, which reached 100.24 Ha as represented in Figure 4. In these years the government has become more massive in handling the estuary of Porong River. The island of Sarinah that is formed today becomes a new icon that invites tourists. The island is used *wanamina* or silvo-fishery where it functions as mangrove forest on one side and pond on the other side.

Figure 4. Map of Sediment and Land Changes Year 2010-2016

The addition of land area in the estuary of Porong River between 2000-2006, 2006-2010, and 2010-2016 has different patterns. The biggest change occurred between 2000 and 2006 with a total change of 149.4 Ha, then it changed in 2010-2016 amounted to 100.24 Ha, and the change in the year 2006-2010 amounted to 93.79 Ha. The change in 2000-2006 had the greatest change since land use change in early 2000 was considerable. This allows for more sediment input if the use of agricultural land is reduced.

4. Conclusion and Recommendation

The spatial distribution of sediment at Porong River estuary has undergone quite a drastic change since before the existence of Lapindo until afterwards. Some algorithms are used to calculate SSC values in 2000, 2006, and 2010 from the SSC value regression in 2016. However, the resulting SSC values did not have very strong correlation. Sediment concentration at Porong River estuary did not have a significant influence with Lapindo mud. In addition to the river flow is too far, also because the sediment concentration in the estuary is influenced by various factors that are dynamic in a short time, especially marine activities.

The development of sediment distribution and land area at Porong River estuary in 2000- 2006 was very large, as big as 149.4 Ha, followed by 100.24 Ha in 2010-2016, and 93,79 Ha in 2006-2010. Thus changes are affected by several factors such as land use change in the Porong River sub-watershed, input of Lapindo mud sediment, also marine activities. In addition, the government's efforts in developing the delta that has been formed also increase the area of the delta.

The large amount of sediment input from Lapindo mud which flow into the Porong River estuary resulted in the formation of a new delta, now called Sarinah Island. This new delta is one of the government programs to introduce mangrove and wanamina studies. Thus, it becomes a more separate value for the sustainability of ecosystems in the estuary of Porong River besides maintaining the balance of river flow and estuary, and so both government and the people should maintain it wisely.

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