APPLICATION OF REMOTE SENSING FOR SUSPENDED SEDIMENT MAPPING IN PORONG RIVER

(Aplikasi Penginderaan Jauh untuk Pemetaan Sedimen Tersuspensi di Sungai Porong)

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ABSTRACT

Porong River is a branch of Brantas river which its downstream is border to Sidoarjo and Pasuruan towns. Since the occurrence of hot mud volcano overflow in Sidoarjo, Porong River has role of draining the sediment into Madura Strait. This paper discusses the concentration of suspended sediment in the Porong River, especially Porong River Estuary, using remote sensing methods. Sedimentation that can be observed by remote sensing method is suspended sediment. The determination of suspended sediment was by changing radians values into reflectance values, then used a variety of algorithms to determine the value of the suspended sediment. The data used in this research was a medium-resolution satellite image data, ASTER image year 2005 to 2008. The algorithm used was developed by Budhiman (2004). The result of data processing and analysis of suspended sediments obtained that suspended sediment in Porong River during the period of 2005 and 2006 were dominated by sediment class 50 - ≤ 100 mg/l, while in 2008 were dominated by class of >200 mg/l.

Keywords: Porong River, suspended sediment, remote sensing, ASTER, Budhiman Algorithm

INTRODUCTION

Porong River is a branch of Brantas River, which has a 51 kms longitudinal, headwaters in Mojokerto, downstream is border of Sidoarjo and Pasuruan town, flows eastward and empties into the Madura Strait. Porong River serves as a flood channel. Porong River stream most of the Brantas River sediment will affect on the sedimentation process, especially in Porong River Estuary, resulting the inhibition of the river flow and make advance the position of the river estuary.

Beside the inhibition of the river flow to Porong River Estuary, another cause of sedimentation in Porong River Estuary is tidal processes and differences of density between sea water and river water. Current and wave dynamics and geometry of the river estuary often lead to a more rapid and higher sedimentation processes (Advend, 2006; Li and Gao, 2008). At the end of May 2006, there was a mud volcano activity in PT Lapindo Brantas drilling locations at Renokenongo Village, Porong district, Sidoarjo. This mud flow caused has flooded to some areas around Porong. A solution to this problem is removing the mud volcano to Porong River, which directly increase the amount of sediment flows in Porong River that can affect to the morphology of Porong River Estuary.

Therefore, a study of sedimentation in Porong needs to be done, one of them is by using remote sensing technology, i.e. ASTER satellite image that has a medium resolution of between 15 meters to 90 meters for mapping the sedimentation. Sedimentation which can be observed by remote sensing technology is suspended sediment (Lillesand and Kiefer, 1994; Kishino, 2005).
Sedimentation can be described well by using a red band that has been converted into reflectance value to eliminate atmospheric effects (Li and Gao, 2008; Solihuddin, 2008).

**METHODS**

**Study Site**

The study area is located at the downstream of Porong River that border Sidoarjo-Pasuruan, and Sidoarjo east coast. Precisely at coordinates 7° 32' 37.349" S 112° 47' 13.425" E to 7° 34' 8.626" S 112° 52' 23.411" E as shown in **Figure 1**. This study is carried out by using level 1B ASTER satellite image data from 2005 to 2008, dated March 11, 2005, July 1, 2006, and May 19, 2008. Field data sample were obtained from 18 samples of data taken at the depth between 1-4 meters and were collected on June 11, 2009.

![Figure 1. Study site.](image)

**Methods**

The data processing started with image corrections that consisted of geometric and radiometric corrections, radiometric correction by changing the value of Digital Number to reflectance values as shown in **Figure 2**. Based on Abrams and Hook (1998), data raddians (LRAD) were calculated using formula in **Equation 1**. While the reflectance data (RTOA) were calculated using the **Equation 2**, which is calculation of multiplier DN variable. Substitution of **Equation 2** into **Equation 3** resulted formulas in **Equation 4** and **Equation 5**.

\[
\text{LRAD} = (\text{DN}-1) \times \text{Unit Conversion Coefficient (UCC)}\ldots(1)
\]

\[
R = (\pi \times \text{LRAD} \times d_2) / (\text{ESUNi} \times \cos(z)) \ldots\ldots(2)
\]

\[
d = (1-0.1672 \times \cos(\text{radians}(0.9856 \times (\text{Julian Day}-4)))) \ldots\ldots(3)
\]

\[
R = ((\text{DN}-1) \times \text{UCC} \times \pi \times d_2)/(\text{ESUNi} \times \cos(z)) \ldots\ldots(4)
\]

\[
a = (\text{UCC} \times \pi \times d_2) / (\text{ESUNi} \times \cos(z)) \ldots\ldots(5)
\]

where:

\[
\begin{align*}
\pi & = 3.14159 \\
z & = 900 - \text{solar elevation angle}
\end{align*}
\]

\[
\text{Esun} = \text{Solar Irradiance Atmospheric}
\]

\[
a = \text{variable multiplier (DN-1)}
\]

The main area of this study is shallow water, therefore separation of the water and the land portion must be done at the beginning by using a masking process. The masking process is done by looking at a range of maximum and minimum brightness value on the object. Brightness impairment occurs at near infrared wavelengths about 1.4 to 2.7 lm, which this does not happen on the ground object (mainland). At channel 4, the electromagnetic radiation waves do not penetrate into the body of water (Campbell, 1987; Lillesand and Kiefer, 1994). Therefore, band 4 is used as a reference in the masking process. Band 4 produces a very dark brightness values on the display image, so the boundary between water and land can be seen clearly. Band 3 is used as reference ASTER image masking process. The algorithm is shown at **Equation 6**.

\[
\text{if } i_1 < 30 \text{ then } i_2 \text{ else null} \ldots\ldots(6)
\]

where,

\[
i_1 = \text{band 3},
\]

\[
i_2 = \text{band 1, band 2}
\]

After the image masking was completed, an image enhancement was performed. Another algorithm used to calculate the TSS in the image. The method used is a non-empirical method, which uses a pre-existing algorithm by assuming that the study area is almost the same. The algorithm used is Budhiman algorithm (Budhiman, 2004). The algorithm uses irradiant reflectance values (R(0-)) of the red band as input as shown at **Equation 7**.

\[
\text{TSS (mg/l)} = 8.1744 \times \exp(23.738 \times \text{red band}) \ldots\ldots(7)
\]

where:

\[
\text{TSS} = \text{total suspended sediment}
\]

Red band = reflectance band 2

The new image resulted from the application of the algorithm then was classified to obtain TSS values class. The results of TSS classification are:

1. Class 1: classification of sediment values in the range of \( \leq 50 \text{ mg/l} \).
2. Class 2: classification of sediment values in the range of \( 50 - \leq 100 \text{ mg/l} \).
3. Class 3: classification of sediment values in the range of \( 100 - \leq 150 \text{ mg/l} \).
4. Class 4: classification of sediment values in the range of \( 150 - \leq 200 \text{ mg/l} \).
5. Class 5: classification of sediment values in the range of \( > 200 \text{ mg/l} \).

The field data collection was processed with aims to determine the condition of TSS in the field.
and the general condition of the waters (Santoso, 2006). The field data used as a basis for interpretation of satellite imagery that represents the area in order to support the process of making a map of TSS.

![Figure 2. Data processing flowchart.](image)

**RESULTS AND DISCUSSION**

**Data Validation**

Correlation analysis is used to determine the relationship between field sediment value and sediment processed image, whereas regression analysis is used to determine functional relationship between field sediment value and image sediment value, regression analysis using simple linear regression. Hypothesis based on ANOVA (F-test) by taking the standard 95% confidence level (α = 5%).

In this analysis, image sediment value taken from ASTER image data in 2008, retrieval of image data aimed for testing the suitability of image sediment value to field data is shown in Table 1. Based on the results, a test is taken to check whether image sediment value is closely related with sediment value obtained from laboratory sample test results of sea water. Here is a comparison of sediment value taken from image data with value of sea water sediment samples obtained from field on June 11, 2009.

Based on Table 1, obtained a correlation between field sediment value and TSS image value as follows on Table 2.

Estimation of sediment shows a correlation coefficient (R) for 0.678 showed on Table 2, showing a low degree relationship between field sediment and image sediment. While the value of determination coefficient (R²) shows the regression equation for 0.460 and can be used to explain the relationship between field sediment with image sediment factors.

A change in sediment values in the image that was affected by field sediment value was 46.0%, while the rest was influenced by other factors. With ANOVA test (F-test), F-Calculate result is 5.971, the significance value was 0.045, so the significance F < α values (0.05), means that Ho is rejected. Thus, in 95% confidence interval, there is a linear relationship between field sediment and image sediment. Based on the regression coefficients and constants obtained regression model Y = 2.983x - 0.377.

**Table 1. Estimates of TSS image value with laboratory test sample of sea water.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Coordinates E, N</th>
<th>Sediment value of 2008 mg/l</th>
<th>Field sediment value 2009 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7° 20’ 8.3006” N; 112° 50’ 44.629”</td>
<td>98</td>
<td>360</td>
</tr>
<tr>
<td>2</td>
<td>7° 22’ 20.715” N; 112° 50’ 27.081”</td>
<td>75</td>
<td>280</td>
</tr>
<tr>
<td>3</td>
<td>7° 23’ 41.759” N; 112° 50’ 19.657”</td>
<td>72</td>
<td>288</td>
</tr>
<tr>
<td>4</td>
<td>7° 25’ 4.259” N; 112° 50’ 22.216”</td>
<td>98</td>
<td>172</td>
</tr>
<tr>
<td>5</td>
<td>7° 28’ 38.432” N; 112° 50’ 43.067”</td>
<td>115</td>
<td>156</td>
</tr>
<tr>
<td>6</td>
<td>7° 30’ 11.848”; 112° 51’ 7.431”</td>
<td>348</td>
<td>116</td>
</tr>
<tr>
<td>7</td>
<td>7° 33’ 29.444”; 112° 53’ 40.005”</td>
<td>340</td>
<td>124</td>
</tr>
<tr>
<td>8</td>
<td>7° 34’ 29.248”; 112° 55’ 42.647”</td>
<td>72</td>
<td>52</td>
</tr>
<tr>
<td>9</td>
<td>7° 31’ 46.481”; 112° 55’ 20.628”</td>
<td>89</td>
<td>52</td>
</tr>
<tr>
<td>10</td>
<td>7° 29’ 30.417”; 112° 53’ 47.153”</td>
<td>19</td>
<td>146</td>
</tr>
<tr>
<td>11</td>
<td>7° 26’ 51.159”; 112° 53’ 9.814”</td>
<td>81</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>7° 24’ 13.982”; 112° 53’ 3.145”</td>
<td>49</td>
<td>88</td>
</tr>
<tr>
<td>13</td>
<td>7° 21’ 26.026”; 112° 53’ 13.225”</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>14</td>
<td>7° 18’ 51.788”; 112° 53’ 27.310”</td>
<td>20</td>
<td>144</td>
</tr>
</tbody>
</table>

Table 2. Correlation analysis of TSS and field data.

<table>
<thead>
<tr>
<th>Analysis</th>
<th>ASTER 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation coefficient (R)</td>
<td>0.678</td>
</tr>
<tr>
<td>Determination coefficient ($R^2$)</td>
<td>0.460</td>
</tr>
<tr>
<td>F-Calculate</td>
<td>5.971</td>
</tr>
<tr>
<td>Significance F</td>
<td>0.045</td>
</tr>
<tr>
<td>Regression coefficients</td>
<td>2.983</td>
</tr>
<tr>
<td>constants</td>
<td>-0.377</td>
</tr>
</tbody>
</table>

Suspended Sediment Distribution

ASTER image acquisition on March 11, 2005 classified TSS that was divided into five classes: Class ≤ 50 mg/l with a distribution along the coastal of Sidoarjo-Pasuruan, dominant heading eastwards towards Madura Strait, Class 50 - ≤ 100 mg/l with a distribution along Porong River until Porong River Estuary and along the coastal of Sidoarjo-Pasuruan, class 100 - ≤ 150 mg/l with a distribution along the coastal of Sidoarjo-Pasuruan, class 150 - ≤ 200 mg/l that evenly spread along the coastal of Sidoarjo-Pasuruan, and class > 200 mg/l with a distribution along the coastal of Sidoarjo-Pasuruan, as shown in Figure 3.

ASTER image acquisition on July 1, 2006 could classified TSS that was divided into five classes: Class ≤ 50 mg/l with a distribution along Porong River and spreading along the coastal of Sidoarjo-Pasuruan, Class 50 - ≤ 100 mg/l and 100 - ≤ 150 mg/l with a distribution along the coastal of Sidoarjo-Pasuruan, class 150 - ≤ 200 mg/l and class > 200 mg/l are in most northern coastal of Sidoarjo, as shown in Figure 4.

ASTER image acquisition on May 19, 2008 could classified TSS that was divided into four classes: Class 50 - ≤ 100 mg/l, 100 - ≤ 150 mg/l and 150 - ≤ 200 mg/l with a dominant distribution along the coastal of Sidoarjo-Pasuruan towards the Madura Strait. Class of > 200 mg/l is in the class distribution Porong River until Porong River Estuary and along the estuary, as shown in Figure 5.

The results of the ASTER image classification of March 11, 2005; July 1, 2006; and May 19, 2008 shows that the distribution of suspended sediment concentration from those years tends to increase sharply, especially in Porong River until Porong River Estuary. This can be seen from a comparison of the extent of the distribution of sediment on Table 3.

Table 3. Size comparison of TSS based on the classification.

<table>
<thead>
<tr>
<th>Class (mg / l)</th>
<th>2005 (ha)</th>
<th>2006 (ha)</th>
<th>2008 (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 50</td>
<td>33396.52</td>
<td>30382.92</td>
<td>0</td>
</tr>
<tr>
<td>50-≤100</td>
<td>5604.437</td>
<td>7029.905</td>
<td>7917.212</td>
</tr>
<tr>
<td>100-≤150</td>
<td>3115.201</td>
<td>4757.609</td>
<td>33811.67</td>
</tr>
<tr>
<td>150-≤200</td>
<td>1107.804</td>
<td>1333.9</td>
<td>1757.678</td>
</tr>
<tr>
<td>&gt;200</td>
<td>1096.289</td>
<td>1005.629</td>
<td>1044.665</td>
</tr>
</tbody>
</table>

CONCLUSION

Test results of the algorithms used to calculate sedimentation is described by linear regression analysis between results of algorithm on images and field data. The result of determination coefficient ($R^2$) is 0.460 against field data. This means that changes in the TSS image values are influenced by field sediments value is 46.0 %, while the rest is influenced by other factors. Low correlation between field measurement and image
calculation shows that algorithm used is less appropriate when applied to suspended sediment calculation content in Porong River, especially Porong River Estuary. Therefore, further study is needed to obtain the appropriate algorithm to apply in the Porong River Estuary.

Based on ASTER image data for 2005, 2006 and 2008, it is known that suspended the sediment distribution concentration in Porong River Estuary tends to dynamics. An increase in the suspended sediment content on sediment class ≤ 50 mg/l to class 100 - ≤ 150 mg/l in 2008. Especially in Porong River suspended sediment increase sharply, in 2005 and 2006 dominate class is 50 - ≤ 100 mg/l, while in 2008 dominate class is >200. Further sedimentation study should be supported by other data such as hydro-oceanographic data, erosion upstream data and calculations of sediment supply, to obtain information regarding sediment supply that flowing from the river into the sea.

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REFERENCES


