Evaluation of Multitemporal Satellite Images to Identify Total Suspended Solid Change in Madura Strait Waters

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ABSTRACT

Total Suspend Solid (TSS) is one of physical parameters in waters which are very dynamic depended on upland and the waters condition. The TSS spatial analysis using multitemporal image satellite data in Madura Strait waters was conducted to derive suspended sediment distribution and its sediment dynamics. The method used in this study is TSS algorithm, the application of image data to get the sediment distribution and its density supported by several field measurement results. Based on the research, the distribution concentration of suspended sediment in Madura Strait waters is dynamics, and it can be seen from the changing of sediment concentration widespread in many times of recording. However it was totally occurred the increasing widespread in highly suspended sedimentation concentration. The climate and hydro-oceanography (wave, tidal, current) are the parameters that influence toward distribution dynamics of suspended sediment widespread in the waters.

KEY WORDS: TSS, Satellite Image, Hydro-Oceanography.

INTRODUCTION

Madura strait waters area has a close corelation with coastal environment condition of Bengawan Solo Basin. As the fast development of Surabaya and Gresik cities, such as the development of coastal area for modern residential and industry areas, the condition changed the coastal system in this area. The Coastal land reclaimed for industry and residential areas is the first priority of development program in this area. The conservation of mangrove area for making an industry area and fishpond caused land erosion in Madura strait lowland. Other impacts are silting up and sedimentation in water ways of Madura strait. Wave forced by highly speed ships causes coastal erosion and turbidity of sea water arround Madura strait waters.

One of the Remote Sensing application in sedimentation is the monitoring of TSS change rate in water ways (Budiman, 2004; Suparka et al., 2005). TSS is a solid matter causing turbidity in water and it is also an undissolved solid matter which can not directly settle. The suspended solid matter is composed of particles having dimension more than 1 µm, the examples are clay, soft sand, organic matter, and others.

The direct observation in the field study for measuring TSS change rate will need a long time measurement period and expensive cost. So it is needed a method for calculating TSS change rate fastly and accurately. This research used remote sensing method to identify suspended sediment distribution in Madura Strait Waters. The objective of this research is to know suspended sediment distribution in Madura Strait Waters and its sediment dynamics.

METHODOLOGY

Data collection

Data collected in this research are as follow:

- Landsat 5 TM satellite image 118 path and 065 row July 24th 1994.
- Landsat 7 ETM+ satellite image 118 path 065 row August 17th 2000 and May 22nd 2003
- ASTER satellite image 118 path 181 row and 3 swath February 10th 2007.
- Indonesian Topographic Map sheet 1608 (31-34) and sheet 1609 (11-12) scala 1:25 000 Bakosurtanal edition 1999.
- The percentage of wind and wave data collected from Meteorology Station (BMG) Tanjung Perak Surabaya in 10 years period (1995 – 2004)

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The secondary data of tide and wave pattern collected from hydrodinamic model simulation result using ADCIRC modul from software 9.0 (Suparka, E, 2005)

Field data such as sea water sample and coordinat points. The Sampling of sea water is carried out by using nasen bottle instrument in deep water circa ± 2 meter. The recording of Sample point coordinat used GPS navigation instrument with accuracy ± 15 meter.

Data Processing

Image Geometric correction

The geometric correction of Landsat image use registration method, that is by registrating of similar points between uncorrected image with coorected image. Every geometric correction of Landsat image use 4 Ground Control Points (GCP) placed on the right and left corner, upside and downside. It is conducted, in order that the image ectivicated spreadly. The Coordinat system used by rectification processing is Universal Transverse Mercator 49 Zone with World Geodetic System 1984 (WGS 84) as ellipsoid reference.

The geometric correction process of ASTER image is little difference with Landsat image, where the geometric platform of ASTER sensor has not only more control point (10 points) but also completed with geographic coordinate reference from raw DEM data by GTOPO30 1997 data, so it can be said that the result of ASTER image product was corrected 3 D (X,Y,Z) from its sensor platform. Geometricly the ASTER image has more geometric accuracy than Landsat image. Though, there is an important step for geometric correction in this data, that is an input of angle rotation parameter, which this value is the correction of sun inclination angle and sensor angle during recording. This step is often called as image rotation with value of inclination angle can directly be read in header of ASTER image.

Image radiometric correction.

The radiometric correction by Landsat image use radiometric correction method from handbook for Landsat 5 TM image, that is the changing of digital number value (DN) to radiance value by gain and offset from header file, and than change radiance value to reflectance value by solar irradianace, sun elevation angle and sun-earth distance.

Algorithm used for converting DN value to radiance value is as follow:

\[ L_\lambda = \text{gain} \times DN + \text{offset} \]

with :

\[ L_\lambda = \text{radiance spectral in } W/(m^2 \cdot sr \cdot \mu m) \]

Algorithm used for converting Radiance value to reflectance radiance is as follow:

\[ \rho_p = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos \theta} \]

where:

\[ \rho_p = \text{reflectance} \]
\[ L_\lambda = \text{radiance spectral in } W/(m^2 \cdot sr \cdot \mu m) \]
\[ d = \text{the distance from earth to sun in astronomical unit} \]
\[ ESUN_\lambda = \text{sun irradianace}. \]
\[ \theta = \text{sun zenit angle in degree unit}. \]

Radiometric correction on ASTER image use an algorithm developed by California Institute of Technology, for converting DN value to reflectance value, it is needed offset value and scala factor.

\[ R = DN \times \text{FaktorSkala} + \text{offset} \]

with :

\[ R = \text{reflectance value} \]

TSS Algorithm

TSS parameter from Landsat and ASTER data derivated from Budiman (2004), it is a result of research in Delta Mahakam waters. That algorithm use irradiant reflectance value (R(O-)) from red band as input data, but in this research it is used reflectance value of red band and corrected atmospheric. The following is Algorithm used:

\[ \text{TSS (mg/l)} = A \times \exp (5 \times R(0-) \text{ red band}) \]

with :

\[ \text{TSS} = \text{total suspended solid} \]
\[ R(0-) = \text{irradian reflectance}. \]
Base on the parameter obtained, the derivation of TSS algorithm for each image data is as follow:

- **Landsat 5 TM**: \[ \text{TSS (mg/l)} = 8.2054 \times \exp(23.769 \times \text{red} - \text{band}) \]
- **Landsat 7 ETM**: \[ \text{TSS (mg/l)} = 8.1429 \times \exp(23.704 \times \text{red} - \text{band}) \]
- **ASTER**: \[ \text{TSS (mg/l)} = 8.1744 \times \exp(23.738 \times \text{red} - \text{band}) \]

**Image classification**

Image classification is aimed for clustering TSS value in certain class. Algorithm used for classifying on tool formula editor ER Mapper 7.0:

- if \( i1 > 10 \) and \( i1 < 25 \) then 1 else if \( i1 >= 25 \) and \( i1 < 40 \) then 2 else if \( i1 >= 40 \) and \( i1 < 55 \) then 3 else if \( i1 >= 55 \) and \( i1 < 70 \) then 4 else if \( i1 >= 70 \) and \( i1 < 85 \) then 5 else if \( i1 >= 85 \) and \( i1 < 100 \) then 6 else if \( i1 >= 100 \) and \( i1 < 115 \) then 7 else if \( i1 >= 115 \) then 8 else null.

**RESULTS AND DESCRIPTION**

**Image Geometric correction**

The biggest result of geometric correction by Landsat image on maximum RMS error is 0.28 pixel. That means displacement maximum after rectification is 0.28 x 30 meter = 8.4 meter on the ground. This value is still in the tolerance value of Landsat image (not more than 1 pixel). The error tolerance maximum for Landsat image is not more than 1 pixel (30 m x 30 m).

As the above description in the data processing method, the ASTER image product has corrected 3D (X,Y,Z) from its sensor platform, so for geometric correction for this data, it is only input parameter of sensor inclination angle that it is usually called image rotation. The EOS (Earth Observing System) as a satellite management claim that the accuracy geometric of ASTER image by RMSerror <0.2 pixel for minimum scale mapping 1 : 50 000. Because of the reason, then it is used as the base that geometric correction of ASTER Image is only appropriate at the phase of rotation for mapping accuracy in this research.

**Distribution Image of TSS**

Base on the average values (means) of spectral reflectance 3rd Band of Landsat image and 2nd Band of ASTER, and with considering the laboratory test result, the TSS content value in this research is classified into 8 classes with details as displayed in Table 1.

<table>
<thead>
<tr>
<th>No</th>
<th>Class</th>
<th>Image reflectance (R) value</th>
<th>Suspended Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>10 ≤ R &lt; 25</td>
<td>10 mg/l ≤ SS &lt; 25 mg/l</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>25 ≤ R &lt; 40</td>
<td>25 mg/l ≤ SS &lt; 40 mg/l</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>40 ≤ R ≤ 55</td>
<td>40 mg/l ≤ SS ≤ 55 mg/l</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>55 ≤ R ≤ 70</td>
<td>55 mg/l ≤ SS ≤ 70 mg/l</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>70 ≤ R ≤ 85</td>
<td>70 mg/l ≤ SS ≤ 85 mg/l</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>85 ≤ R ≤ 100</td>
<td>85 mg/l ≤ SS ≤ 100 mg/l</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>100 ≤ R &lt; 115</td>
<td>100 mg/l ≤ SS &lt; 115 mg/l</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>R ≥ 115</td>
<td>SS ≥ 115 mg/l</td>
</tr>
</tbody>
</table>

According to Landsat image 5 TM July, 24th 1994, the Madura strait waters is classified into 6 suspended sediment classes, from 2nd class until 8th class (see Figure 1.). Every class has area widespread as follow:

- The width of class 2 is 1,052.699 Ha with the distribution in north Madura Strait near Java Sea.
- The width of class 3 is 4,199.668 ha with the distribution in north of Madura Strait near Arosbaya beach, Bangkalan district - Madura.
- The width of class 4 is 17,351.685 ha with the distribution in Teluk Lamong, a part of water ways Gresik and around Surabaya east coast.
- The width of class 5 is 24,207.647 ha with the distribution in almost all Madura strait waters especially in water ways.
- The width of class 6 is 3,608.613 ha with the distribution in Surabaya north beach and in around Bengawan Solo River estuary, Ujung Pangkah.
- The width of class 7 is 17.483 ha with the distribution in around Bengawan Solo estuary, Ujung Pangkah.
- The width of class 8 is 20.075 ha and it is identified as a cloud.
Landsat 7 ETM+ in the year 2000
According to JPL NASA (2002) Landsat 7 ETM+ image on August 17th 2000, Madura strait waters is classified into 5 classes of suspended sediment, that is class 4 until class 8 (see Figure 2.)
- The width of class 4 is 0.054 Ha with the distribution of points in several research locations.
- The width of class 5 is 1,690.498 ha with the distribution in north of Madura strait waters near Java sea.
- The width of class 6 is 5,419.897 ha with the distribution in north of Madura strait waters around Arosbaya beach – Bangkalan District, Madura.
- The width of class 7 is 14,697.462 ha with the distribution in a part near Sedayu beach – Gresik district, Teluk Lamong, Gresik water ways, and Surabaya east coast.
- The width of class 8 is 28,363.043 ha with the distribution in almost all Madura strait waters, mainly in the water ways, Surabaya north coastal, and around estuary of Bengawan Solo river, Ujung Pangkah.

Landsat 7 ETM+ in the year 2003
According to Landsat image on Mei 22th 2003, Madura strait waters is classified into six suspended sediment classes, that is class 3 until class 8 (see Figure 3.). Every class has area widespread as follow:

<table>
<thead>
<tr>
<th>Class N.</th>
<th>Area (Ha)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1,638.354</td>
<td>North of Madura strait waters near Java sea.</td>
</tr>
<tr>
<td>4</td>
<td>12,593.258</td>
<td>North of Madura strait waters near Arosbaya beach, Bangkalan District - Madura.</td>
</tr>
<tr>
<td>5</td>
<td>19,277.482</td>
<td>All waters, specially water ways and Surabaya east coast.</td>
</tr>
<tr>
<td>6</td>
<td>3,608.613</td>
<td>Side of Sedayu beach, Bungah Bangkalan, Teluk Lamong and Surabaya east coast.</td>
</tr>
<tr>
<td>7</td>
<td>2,129.578</td>
<td>Side of Sedayu beach and Ujung Pangkah shallow waters</td>
</tr>
<tr>
<td>8</td>
<td>438.893</td>
<td>Around Bengawan Solo estuary, Ujung Pangkah</td>
</tr>
</tbody>
</table>
ASTER year 2007.

According to ASTER image on February 10th 2007, Madura strait waters is classified into eight suspended sediment classes, that is class 1 untill class 8 (see Figure 4). Every class has area widespread as follow:

<table>
<thead>
<tr>
<th>Class N.</th>
<th>Area (Ha)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3,164.371</td>
<td>North of Madura strait waters near Java sea.</td>
</tr>
<tr>
<td>2</td>
<td>13,000.566</td>
<td>North of Madura strait waters and Gresik water ways</td>
</tr>
<tr>
<td>3</td>
<td>16,645.416</td>
<td>Shallow waters in Madura strait waters and Surabaya east coast.</td>
</tr>
<tr>
<td>4</td>
<td>8,109.129</td>
<td>Side of shallow waters Madura strait.</td>
</tr>
<tr>
<td>5</td>
<td>959.516</td>
<td>Side of Sedaya beach,Arosbaya, Lamong bay and shallow waters of Surabaya east coast.</td>
</tr>
<tr>
<td>6</td>
<td>438.893</td>
<td>Near of Bengawan Solo estuary, Ujung Pangkah,Arosbaya, Lamong bay, Surabaya east coast.</td>
</tr>
<tr>
<td>7</td>
<td>1,406.159</td>
<td>Ujung Pangkah ashore and Arosbaya - Bangkalan.</td>
</tr>
<tr>
<td>8</td>
<td>604.165</td>
<td>Lamong bay, estuary of Bengawan Solo river, Ujung Pangkah.</td>
</tr>
</tbody>
</table>

Evaluation of suspended sediment distribution by satellite image

Base on the result of classified images (1994, 2000, 2003, 2007) distribution concentration of suspended sediment is tend to dynamics years by years in Madura strait waters. This case can be seen by the comparison of TSS distribution widespread, as the result of image classification such as the following (see Table.2.):

<table>
<thead>
<tr>
<th>No</th>
<th>TSS (mg/l)</th>
<th>Landsat 5 TM 24-07-1994 (hektar)</th>
<th>Landsat 7 ETM+ 17-08-2000 (hektar)</th>
<th>Landsat 7 ETM+ 22-05-2003 (hektar)</th>
<th>ASTER 10-02-2007 (hektar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 – 25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3,164.371</td>
</tr>
<tr>
<td>2</td>
<td>25 – 40</td>
<td>1,052.699</td>
<td>-</td>
<td>-</td>
<td>13,000.566</td>
</tr>
<tr>
<td>3</td>
<td>40 – 55</td>
<td>4,199.668</td>
<td>-</td>
<td>1,638.354</td>
<td>16,645.416</td>
</tr>
<tr>
<td>4</td>
<td>55 – 70</td>
<td>17,351.685</td>
<td>0.054</td>
<td>12,593.258</td>
<td>8,109.129</td>
</tr>
<tr>
<td>5</td>
<td>70 – 85</td>
<td>24,207.647</td>
<td>1,690.498</td>
<td>19,277.482</td>
<td>959.516</td>
</tr>
<tr>
<td>6</td>
<td>85 – 100</td>
<td>3,608.613</td>
<td>5,419.897</td>
<td>3,608.613</td>
<td>3,569.438</td>
</tr>
<tr>
<td>7</td>
<td>100 – 115</td>
<td>17,483</td>
<td>14,697.462</td>
<td>2,129.578</td>
<td>1,406.159</td>
</tr>
<tr>
<td>8</td>
<td>≥ 115</td>
<td>-</td>
<td>28,363.043</td>
<td>437.893</td>
<td>604.165</td>
</tr>
</tbody>
</table>
This condition is mostly related with data recording time by either Terra-ASTER or Landsat satellite. Base on the wind data recording by BMG (Geophysical and Meteorological Board) Tj Perak station in ten years period (1995-2004) indicate that the influence of east wind occurs on May – October months, it means that Surabaya area is dry season. Whereas west wind emerges in November – March month, it means that Surabaya surrounding condition is rainy season. In the rainy season, the discharge of river that flow into Madura strait waters higher than in dry season.

Besides the season factor, the tidal condition at the moment of data acquisition also influence toward sediment concentration. Based on metadata of ASTER Image, time accusation in February 10th, 2007 is in 02:53 GMT or 09:53 local time WIB. However, the accusation time by Landsat image is in 118 path and 065 row is always 09:00 until 12:00 local time WIB (Purwadhi, 2001). Base on tidal prediction by Service Hydrographique et Océanographique de la Marine (SHOM) France for ASTER image has ±1.5 m water surface and 2.2–2.5 m by Landsat image to the high tidal position. The difference of water surface by two images was 0.7–1 meter, so it influence tidal current and also it finally influence suspended sediment concentration in the waters area.

CONCLUSION

Base on all kind image condition, the concentration of suspended sediment distribution years to years in Madura strait waters tends to dynamics. This case can be seen from the comparison of TSS distribution widespread in every classified image.

The season factor deeply influence suspended sediment concentration in Madura strait waters, because the discharge river in rainy season that flows into sea waters is higher than in dry season.

The tidal condition also influence suspended sediment concentration in waters, because pattern and current velocity by tidal sea water is difference, so it also influence the contents carried by suspended sediment.

REFERENCES