STUDY OF MODIS-AQUA DATA FOR MAPPING TOTAL SUSPENDED MATTER (TSM) IN COASTAL WATERS

BAMBANG TRISAKTI[1], PARWATI[1] AND SYARIF BUDHIMAN[1]

Abstract

The MODIS-Aqua data have been studied to map TSM distribution in coastal waters. TSM algorithm model for MODIS data with spatial resolution of 250 m, 500 m and 1000 m was developed by correlating the TSM derived from spectral values of MODIS and the TSM derived from Landsat-7 ETM data using the calibrated algorithm. Statistical test was conducted to see normality of data and level of influence from both parameters. Analysis was conducted to see the change of spectral value from bands of MODIS data with resolution of 1000 m towards the change of level of TSM concentration. The results shows that the TSM algorithm model is in the form of power (X^a) with the highest correlation coefficient is obtained from the correlation between the Landsat TSM value with the quantification of band 1 and band 2 of MODIS data for spatial resolution 250 m, ratio of band 4 and band 3 for spatial resolution 500 m, and ratio of band 13 and 11 for spatial resolution 1000 m. The pattern of TSM distribution in coastal waters can be identified in more accurate using MODIS data with resolution of 250 m and 500 m. The analysis result of the curve of MODIS spectral value data with resolution 1000 m shows that the change of TSM concentration influences significantly to the form of curve of spectral value, especially for band 11 - 16 (visible green, red and NIR).

Keywords : *MODIS-Aqua, Landsat, TSM algorithm model, spatial resolution, curve of spectral value*

I. Introduction

TSM (Total Suspended Matter) is material suspended (diameter > 1 urn) which is clutch to the millipore with diameter 0.45 (Effendi, 2000). In general, TSM consists of mud, grain sand, and small organic matter, which are mostly caused by erosion carried into the water. TSM monitoring is always conducted to find the water quality in the water environment, because the higher TSM concentration provides the higher level of pollution and blocks the light penetration to the water, and then disturbs the photosynthetic processes.

Satellite Remote sensing is an alternative for monitoring water quality, especially sediment distribution (TSM) in the waters (Raharti, 1996). The TSM distributions have been conducted using various remote sensing data with difference sensor characteristics. Hasyim et al. (1997) used band 2 and band 3 of Landsat TM to find TSM distribution in Jakarta Bay, while Budhiman (2004) used

1 Indonesian National Institute of Aeronautics and Space - LAPAN
Jl. Lapan No. 70, Pekayon, Ps. Rebo, Jakarta Timur 13710. email: blris01@yahoo.com

several various bands from some satellite data (Landsat, Aster and SeaWIFs) to develop an algorithm model of TSM in Mahakam Delta, Woerd and Pasterkamp (2004) developed an algorithm model of TSM using, -sirigje band from SeaWIFs data. Matthews.^Q*k (2001) developed an algorithm model o?iI?^M using band ratio 'of airborne multisp&ctrkl data. From these . researches', * it .becotriesi clear that TSM \ distribution iri^Jh^'waleps can be identified ifsihg visible anyZ/NJ'R (Near Infrared) wavelength, whereNlfe can only be used in higher TSM concentration, because of the characteristic of NIR (easily absorbed by water). Report by Li et al. (2003) can support those researches, and it shows that the visible range (0.4 - 0.7 urn) is strongly reflected by the sediment in the waters.

MODIS (The Moderate Resolution Imaging Spectroradiometer) sensor carried by Aqua and Terra satellite is a new generation sensor having a high spectral resolution of 36 bands (hyperspectral), and it is available for remote sensing applications. Study of the use of MODIS data related to water/marine information have been made, for example: various studies about sea surface temperature and chlorophyll distributions, mapping coastal plume using the coefficient of absorption and reflection (Heng, et al, 2004), development of model to detect inundated area (Magsud, et al, 2004) and other various studies. Nevertheless, the research and application of MODIS data for marine application, especially mapping of TSM distribution and ocean color in Indonesian waters are not commonly used.

This study aims to know the ability (sensitivities) of each band from MODIS-Aqua data at 3 (three) different spatial resolutions (250 m, 500 m and 1000 m) to map TSM distribution in coastal waters, and moreover to analyze the ability of hyperspectral bands to find the change of TSM concentration.

II. Study Area

The Study area for monitoring and *in situ* experiment is selected along coastal waters of Cirebon and Brebes Regencies representing Java Sea (Figure 1). The location is selected with the following considerations:

- Many rivers alongside fish pond area as the land cover of the coast and consequently resulting with mount of TSM in this water. Type of this water is included in Case Water 3 (Jerlov, 1976), which is waters with very high turbidity, generally in coastal waters.
- Offshore of Java Sea waters, which is relatively calm does not change drastically the pattern of TSM distribution.

With these considerations, it is expected that the study area represents the coastal waters with high turbidity (TSM) concentration (Case Water 3), and it is simplified in comparison with the TSM distribution pattern between MODIS and Landsat data.

III. Data Characteristics

Primary data are MODIS data of August 18^{.h} 2004 and the Landsat-7 ETM of August 17th 2004. The difference in time acquisition (1 day) between MODIS and Landsat data is caused by the difficulty of obtaining cloud free MODIS data within the same acquisition date.

MODIS data are obtained from AQUA satellite, which are acquired at National Institute of Aeronautics and Space (LAPAN) ground station in Pare-Pare. MODIS data have 3 spatial resolutions of 250 m, 500 m and 1000 m with total of 36 spectral bands.

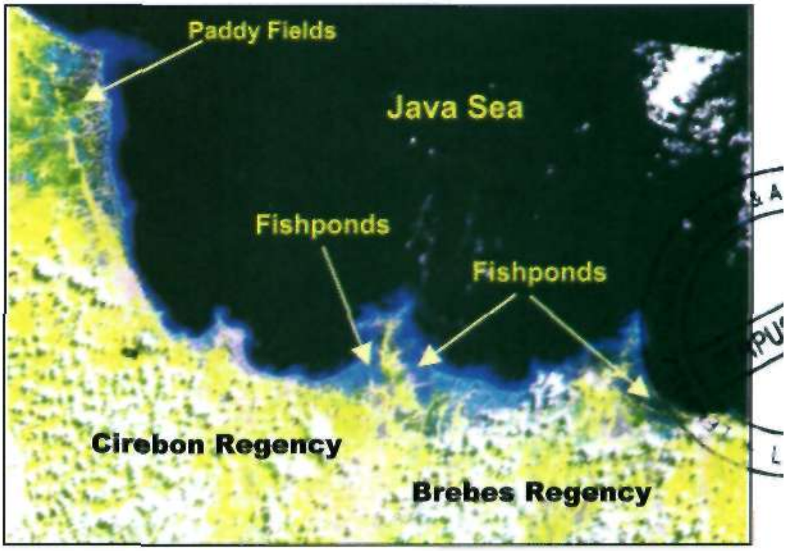


Figure 1. Study area in coastal waters of Cirebon and Brebes regencies (Landsat-7 ETM, June 2001, RGB 543)

Table 1 shows MODIS spectral bands with different spatial resolutions which might be used for mapping the TSM distribution and ocean color. Data accepted are in the form of level IB (radiometric and geometric systematic corrected). Using the HDF reader with special module based on LINUX, data have been atmospheric corrected (Simplied Atmospheric Correction Model) for gas (H20, C02, 03) and the aerosol. The reflectance values are only determined for resolutions of 250 m and 500 m, while data with resolution of 1000 m are still in digital number.

Landsat-7 ETM level IG data obtained from the Data Center LAP AN at Pekayon has 6 multispectral bands with 30 m spatial resolution. One thermal band has 60 m spatial resolution and the panchromatic band has 15 m spatial resolution. Landsat data was in a SLC-OFF condition (having stripping area which does not have value) and based on digital number.

Table 1. MOD1S bands used for mapping TSM

No band	Spectral resolution (m)	Spatial resolution
1	0.620 - 0.670	250 x250 m
2	0.841 - 0.876	250 N 250 m
3	0.459 - 0.479	500 x 500 m
4	0.545 - 0.565	500 x 500 m
X	0.405 - 0.420	1000 x 1000 m
9	0.438 - 0.448	1000x 1000m
10	0.483 - 0.493	1000x 1000m
11	0.526-0.536	1000 x 1000 m
12	0.546-0.556	1000 x 1000 m
13	0.662 - 0.672	lOOOx 1000 m
14	0.673 - 0.683	1000 x 1000 m
15	0.743 - 0.753	1000 x 1000 m
16	0.862 0.877	1000 x 1000 m
17	0.890 - 0.920	1000x 1000 m
18	0.931-0.941	1000 \ 1000 m
19	0.915-0.965	1000x 1000 m

IV. Methodology

The research flowchart is shown in Figure 2. Landsat-7 ETM level IG data (systematic and geometric corrected) were radiometric corrected by transforming the digital number into the reflectance value, then atmospheric corrected using the model of Dark Pixel Subtraction Method (Chavez, et al, 1977). The TSM distribution determined by Landsat uses model in Trisakti (2004), which studie the TSM distribution in the coastal waters of Situbondo Regency, East Java. For MODIS level IB data, since the spectral value has been radiometric and atmospheric corrected (spatial resolution of 250 m and 500 m), the next process was bowtie correction (improving part of overlapping data), systematic geometric correction and overlaying or superimposing required channels in each different spatial resolution. In order to process the training samples, the MODIS data was cropped in the study area and the geometric correction was made related to Landsat data.

The training samples were conducted to more than 40 locations with value of TSM Landsat and spectral value of MODIS data from each spatial resolution (250m, 500 m and 1000m). In each location of sample, spectral bands of MODIS were taken by value of 1 pixel size. On the other hand, TSM value of Landsat-7 ETM was taken by calculating the mean TSM values from several pixels corresponding to the same area as 1 pixel size of MODIS. Training sample should not in the SLC-OFF area of Landsat data, and represent s a wide range of TSM concentration (minimum and maximum values of TSM).

Correlation between spectral values of MODIS bands and TSM values of Landsat was conducted to see the relation pattern and the coefficient determination (R^2). The best correlation was examined statistically to see normality of data and level of influence clearly from both parameters. The new TSM algorithm was used to derive TSM distribution in each spatial resolution of MODIS and later the results were compared with TSM Landsat. If the pattern is different, the process of training sample will be checked (there is a possibility of incorrect training sample in region SLC-OFF, and others). If the pattern is in a good agreement, the algorithm model will be used to yield TSM distribution from MODIS.

The ability of hyperspectral band was also examined by classifying the range of TSM value in MODIS data of 1000m spatial resolution. Then the training sample of spectral values at band 8-19, which are different of TSM range values, was conducted.

V. Results and Discussions

5.1 TSM distribution from Landsat-7 ETM data

The TSM distribution from the Landsat data was classified from Equation 1 and 2 (Trisakti et. al., 2004). This model was developed by calibrating the TSM model of Woerd and Pasterkamp (2004) with the TSM insitu data in north coast of East Java.

Condition Xwoerd ≤ 2.76

$$TSM = 1.0585e^{1.3593X} \quad (R^2=0.82) \qquad (1)$$

Condition $X_{woerd} > 2.76$

$$TSM = 32.918X - 46.616 \quad (R^2=0.74) \qquad (2)$$

where,

$X_{woerd} = (-0.53R_{b2}+0.001)/(0.03R_{b2}-0.059)$

R_{b2} = corrected reflectance value for band 2

The TSM concentrations have widely ranging values where coastal waters have high concentration of the TSM distribution (about 700 mg/1) (Figure 3). This is caused by the number of coastal river estuaries alongside with fishpond and rice fields that are located along the watershed area (see Figure 1). The pattern of TSM existence (sedimentation) in river estuary area is presented with red and yellowish-red color.

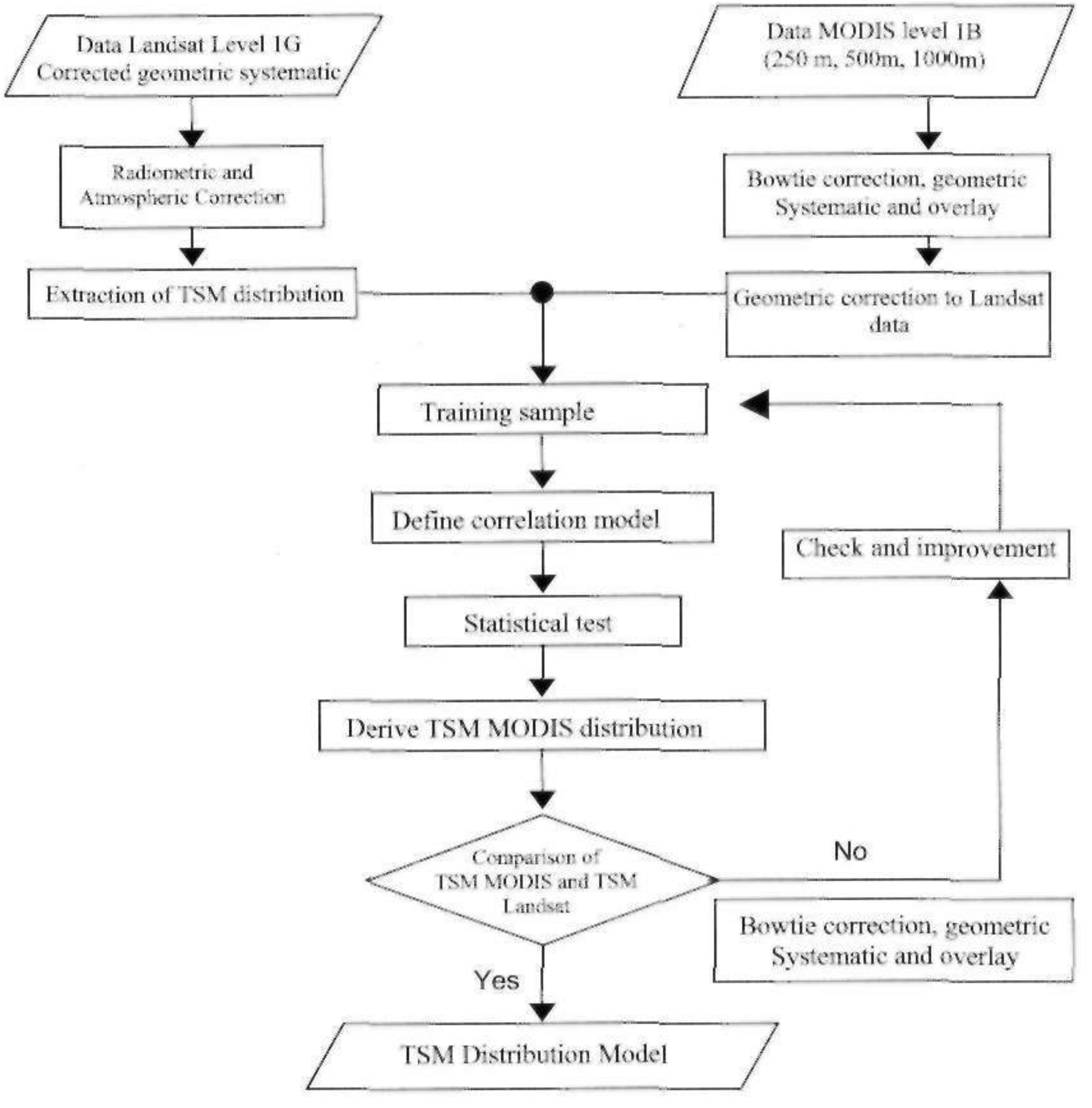


Figure 2. Data processing flowchart

5.2 Study of TSM algorithm for MODIS data with spatial resolution of 250m

The TSM algorithm for MODIS data with spatial resolution of 250 m was applied and processed by making correlation relation between spectral value (reflectance corrected) band 1 and band 2 MODIS with TSM values of Landsat, then choosing the highest correlation. Tables 2 shows the correlation coefficient (R^2), obtained by correlation between spectral values of MODIS and values of TSM Landsat. The Model algorithm is used power (X^a) with considers the order of bottom and top boundary (boundary conditions). For example, if spectral value is 0 (energy is absorbed by waters), TSM will have value of 0 (clear waters). If spectral values increase until a maximum boundary which can be detected by sensor of satellite, the TSM should increase until it reaches the maximum boundary.

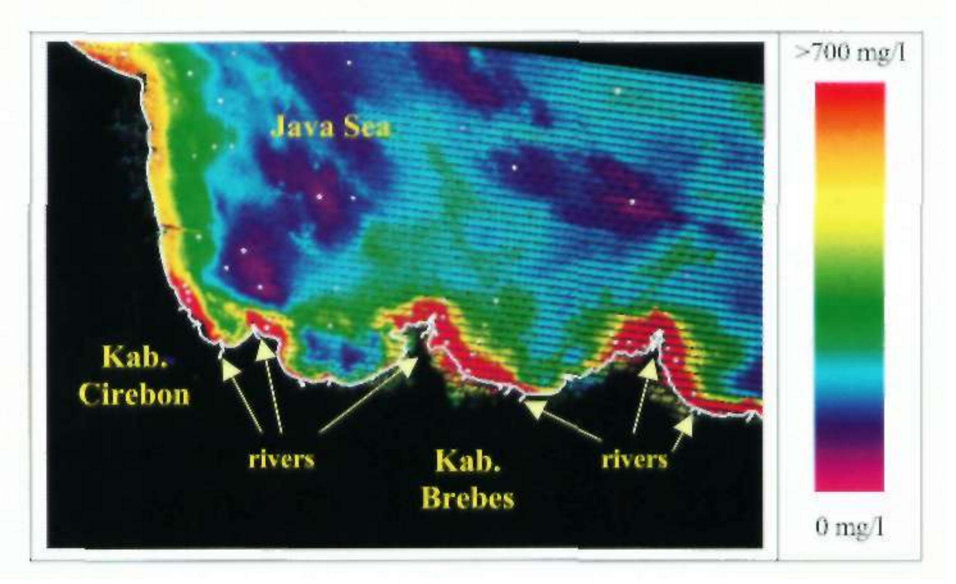


Figure 3. TSM distribution in coastal waters of north coast of Java using Landsat data

Table 2. Correlation coefficient between spectral value ofband 1 (bl) and band 2 (b2) of MODIS 250m with TSM Landsat (power model) from 40 training samples.

Analysis	Variation of MODIS spectral value	R^2
1	bl	0.703
2	b2	0.592
3	bl/b2	0.112
4	b2/bl	0.112
5	bl+b2	0.730
6	bl*b2	0.729
7	(M+b2)/b2	0.109
8	bl^{z}+b2	0.668
1	_(bl+b2)/(bl-b2)	0.119

The result shows that quantification of bl+b2 and bl*b2 have the highest coefficient, compared with others. Those are 0.730 and 0.729 respectively. Here we chose to use the spectral value of b 1 +b2 by considering that for high TSM concentration in coastal waters b2 (NIR) is not only absorbed by waters, but also reflected by suspended particles in underwaters, so that b2 value is important to be consider, but for the low TSM concentration b2 will tend to be absorbed completely (0) so that only bl to be considered. Figure 4 shows correlation graph of bl+b2 and TSM Landsat value. The TSM algorithm model for 250 m is shown as follows:

$$TSM\ (mg/l) = 72743\ (bl+b2)^{23551} \qquad (3)$$

where b 1 and b2 : Reflectance value for band I and band 2 MODIS 250 m.

The Statistical calculation was conducted to investigate data normality and significant level between TSM values of Landsat and spectral value of MODIS. The result shows **that** data distribution is normally and significantly affected.

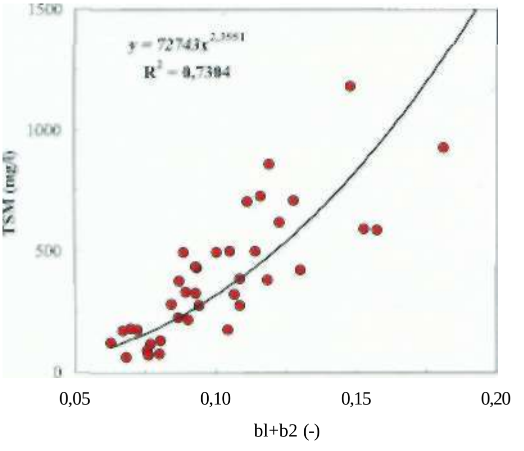


Figure 4. Correlation between speetra values of (bl+b2) MODIS 250 m and TSM Landsat

Figure 5 shows that the TSM distribution derived from MODIS data of 250 m spatial resolution using the algorithm model from equation 3. It shows that coastal waters have high TSM concentration distribution forming pattern of sedimentation, while offshore waters have lower TSM concentration.

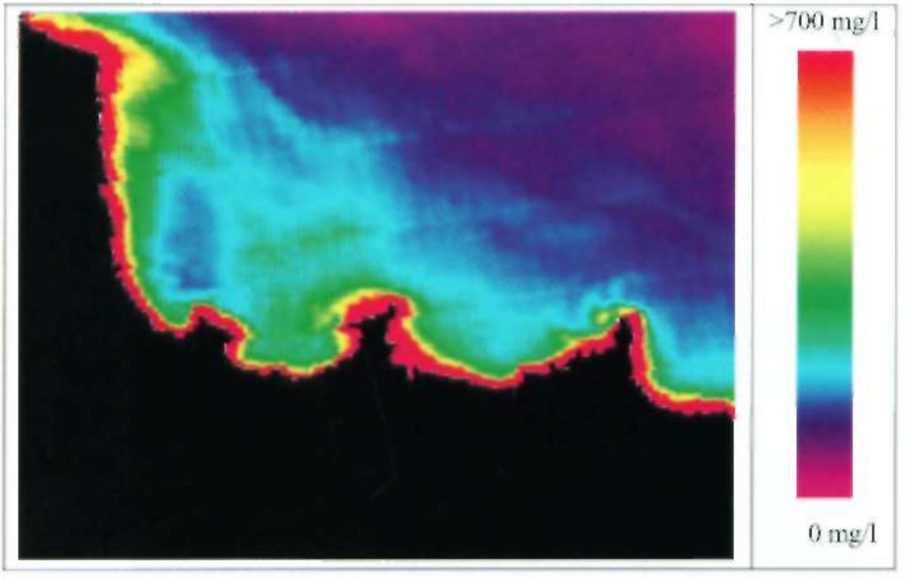


Figure 5. TSM distribution in coastal waters of north coast of Java using MODIS spatial resolution

5.2 Study ofTSM algorithm for MODIS data with spatial resolution of 500m

Table 3 shows the coefficient correlation (R') obtained by correlating the spectral values of band 3 and band 4 with values of TSM Landsat, where model of algorithm of power (X^a) is used with same consideration with the previous 250 m spatial resolution. Band ratio using factor of denominator of band 3 yields high coefficient correlation as seen at analysis no 4, 7 and 8. We chose no 7, that is (b3+b4)/b3, which has the highest coefficient correlation of 0.754.

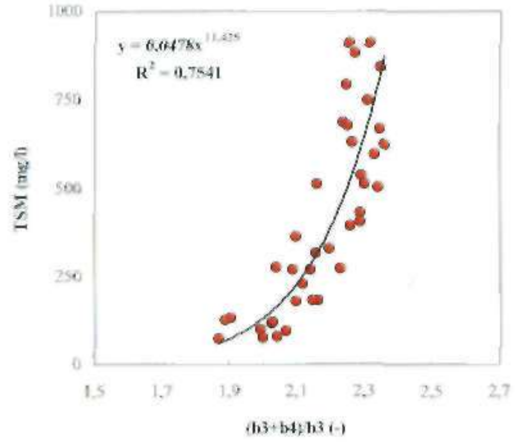
Figure 6 shows correlation graph between (b3+b4)/b3 and TSM Landsat value, and the TSM algorithm for 500 m is shown as follows:

$$TSM(mg/l) = 0.0478 ((b3+b4)/b3)''^{42S} \quad (4)$$

where b3 dan b4 : Reflectance value for band 3 and band 4 MODIS 500 m.

Table 3. Correlation between spectral values of band 3 (b3) and band 4 (b4) MODIS 500 m with TSM Landsat (power model) using 41 training samples

Analysis	Variation of MODIS spectral value	R^2
1	b3	0.011
2	b4	0.532
3	b3/b4	- 0.748
4	b4/b3	0.748
5	b3+b4	0.348
6	b3*b4	0.329
7	(b3-b4)/b3	0.754
8	(b4*b4)/b3	0.663
9	(b3+b4)/(b4-b3)	0.662



1,5 1,7 1,9 2,1 2,3 2,5 2,7

Figure 6. Correlation function between spectral value of (b3+b4)/b3 MODIS 500 m and TSM Landsat

Statistical examination was conducted to investigate data normality and significant level between TSM values of Landsat compared with spectral value of MODIS. The result proved that data distribution is normally, and significantly affected.

Figure 7 shows TSM distribution derived from MODIS data of spatial resolution of 500 m using algorithm model by equation 4. The pattern of TSM, which is in detail enough alongside the coast, is still recognized by MODIS of spatial resolution 500 m. But it should be considered that the level of pixel (its low spatial resolution) influences the softness of the pattern gradation.

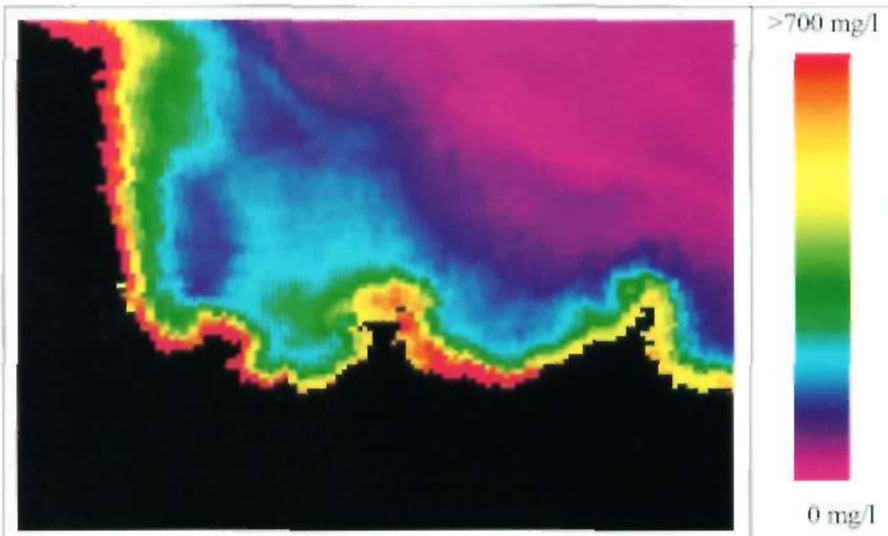


Figure 7. TSM distribution in coastal waters of north coast of Java using MODIS spatial resolution 500 m

5.3 Study of TSM algorithm for .MODIS data with spatial resolution of 1000m

MODIS data with spatial resolution of 1000 m consist of 29 bands (16 thermal bands and 13 bands, covering visible, NIR and SWIR bands). Bands 8 - 1 6 have primary use for ocean color (Jensen, 2003). I Icre, we also consider 3 other bands (that is 17 - 19 bands) to be used as comparator parameters.

Since those are 12 bands that must be studied, the data processing was divided into 2 phases. First phase was comparing the ability of each band to determine the most sensitive band to detect TSM, while the second phase tried to compile bands obtained from first phase with other bands in the form of band ratio model. The band ratio model was used for MODIS data with spatial resolution of 1000 m (digital number), so that the use of this ratio model can be expected to decrease the error of the uncorrected data (radiometric and atmospheric corrected).

A. First phase

Tabic 4 shows the coefficient correlation (R~) obtained from the correlation between spectral values of each MODIS band (band 8-19) and values of TSM Landsat.

Table 4. Correlation coefficient between spectral value of each band (band 8-19) MODIS 1000 m with TSM Landsat (power model) using 25 training samples.

Analysis	Band MODIS	R^2
1	b8	0.018
2	b9	0.095
3	blO	0.149
4	bll	0.383
5	bl2	0.336
6	bl3	0.741
7	bl4	0.746
8	bl5	0.483
9	bl6	0.381
10	bl7	0.285
11	bl8	0.102
12	bl9	0.144

The total training samples for 1000 m spatial resolution data were only 25, which different from other MODIS spatial resolution data that have 40 samples or more. The difference is caused by the size of pixel in this resolution in making the training samples in the coastal region. The result shows that band 13 (0.662 - 0.672 m, red visible) and band 14 (0.673 - 0.683 m, red visible) have highest coefficient, compared with others bands; those are 0.741 and 0.746, respectively. Therefore it can be predicted that band 13 and 14 are very sensitive to detect TSM distribution in coastal waters, henceforth, analysis of phase 2 is conducted to compile band 13 and 14 with other band in the form of ratio model.

B. Second phase

Table 5 shows the value of coefficient (R") obtained from the correlation function between the ratio of band 13 or 14 with TSM Landsat, where algorithm model used is power (X^a).

Table 5. Correlation function between ratio of band 13 or 14 MODIS 1000 m with TSM Landsat (power model) using 25 training samples.

Analysis	Ratio of band MODIS	R^2
1	bl4/b8	0.708
2	b!4/b9	0.705
3	bl4/bl0	0.753
4	bl4/bll	0.791
5	b 14/b 12	0.618
6	bl4/bl3	0.756
7	bl4/bl5	0.237
8	b!3/bl0	0.753
9	b13/b 11	0.803
10	b 13/b 14	0.207

The result shows the ratio of the bands increases the values of coefficient determination. Ratio of band 13 or 14 with higher band number (band 15 - 19) illustrates an effect to decrease the coefficient determination. The highest correlation coefficient was obtained by model ratio using band 11, i.e. bands 13/11 equal to 0.803, and bands 14/11 equal to 0.791. Wc chose to use the ratio of bands 13/11 which has the highest correlation coefficient. This means the variant of TSM Landsat value can be represented 80 % from value of ratio of band 13 and band 11 data of MODIS 1000 m.

Figure 8 shows the correlation between ratio of b13 and bl 1 with value of TSM landsat. The TSM algorithm model for 1000 m is as follows:

$$TSM\ (mg/l) = 316.78\ (b13/b11)^{13.964} \quad (5)$$

where b13 dan b11 : Reflectance value for band 11 and band 14 MODIS 1000 m.

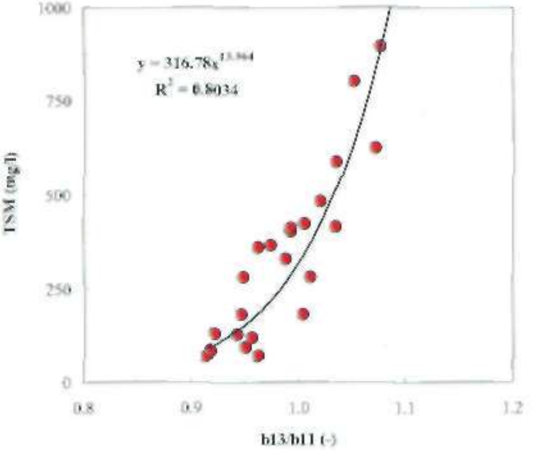


Figure 8. The relationship between ratio of spectral b13/b11 MODIS 1000 m and TSM Landsat

Figure 9 shows the TSM distribution derived from MODIS data with spatial resolution of 1000 m using algorithm from equation 5. The pattern of TSM alongside the coast still can be seen, but very harsh. This is caused by very low spatial resolution.

5.4. Comparison between TSM from MODIS and TSM from Landsat

The comparison aims to verify the TSM distribution of TSM derived from MODIS data for spatial resolution of 250 m, 500 m and 1000 m. Comparison was made by visual interpretation of its pattern of TSM distribution and made training sample of the TSM value at a transect line and shows the distribution pattern.

Figure 10 shows the patterns of TSM distribution derived from MODIS and Landsat satellite in one of offshore close to an estuary. From the visual interpretation it is seen that the TSM derived from the MODIS with spatial resolution of 250 m and 500 m is still able to represent the pattern of TSM distribution, which is fine recognition and close to TSM distribution of Landsat data. Meanwhile the TSM from MODIS with spatial resolution of 1000 m can only provide the level of value of the TSM concentration, but not illustrate the pattern of TSM distribution.

A transect line is drawn as shown in Figure 10 (a) and (b). The value of TSM concentrations were extracted along the transect line, then the distribution pattern of TSM from MODIS and Landsat data were compared.

Figure 9. TSM distribution in coastal waters of north coastal of Java using MODIS spatial resolution 1000m data

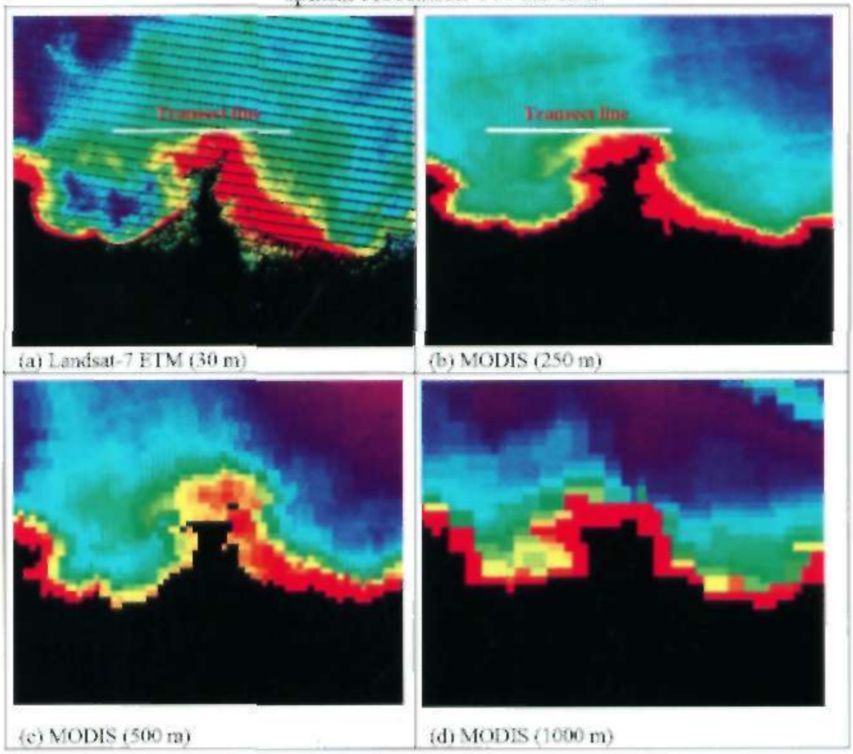


Figure 10. Comparison of TSM distribution ttern in waters near to estuary of study area.

Figure 11 shows the distribution **of** TSM concentration along the transect line in Landsat data and MOD1S with spatial resolution of 250 m, 500 m, and 1000 m. Data from Landsat, MOD1S 250 m and MODIS 500 m show similar in the TSM distribution forming monomodal pattern (one peak) with maximum value about 600 mg/1, whereas MODIS 1000 m shows an up and down distribution form.

From these comparisons, it is clearly understood that the MODIS data with spatial resolution of 250m and 500m are still possible to be used in detecting the TSM distribution in coastal waters, while the MODIS data with spatial resolution of 1000m is too rough to detect TSM distribution in coastal waters.

5.5. Hyperspectral band analysis for TSM concentration changing

The analysis of hyperspectral band is intended to find the change of spectral values from several bands to the change of TSM concentration. MODIS data with 1000m spatial resolution used 12 bands consisting of visible, NIR and SWIR bands. The TSM distribution in the study area analyze by MODIS data with spatial resolution of 1000m was classified into 10 classes with interval 100 mg/1, for example: 0-100 mg/1, 100-200 mg/1, and so on. Then, the spectral values from bands 8 -19 (0.40-0.95 urn) were extracted from different TSM classes to find the change of the curve of spectral value toward the change of TSM concentration.

Figure 12 shows the spectral value of MODIS data with spatial resolution of 1000m for different TSM concentration. It shows that the increasing of the TSM concentration causes the increasing of the spectral value of each band. The significant change of spectral value was confirmed in band 11 band 16 or at the range of wavelength 0.531-0.870 um (visible green, red, and NIR). The condition seems to be constant (no significant change) in bands 8 -10 or in the region of wavelength less than 0.488um (visible blue) and in bands 17-19 or in the region of wavelength more than 0.905 um (SWIR).

The result of the spectral value curve has a similar trend with the model of TSM curve in the offshore of Mahakam Delta (Budhiman, 2004). In the Mahakam Delta waters has a similar type with the study area, which is considered as type of estuarine waters having high TSM concentration or can be classified as Case Water 3 (Jerlov, 1976).

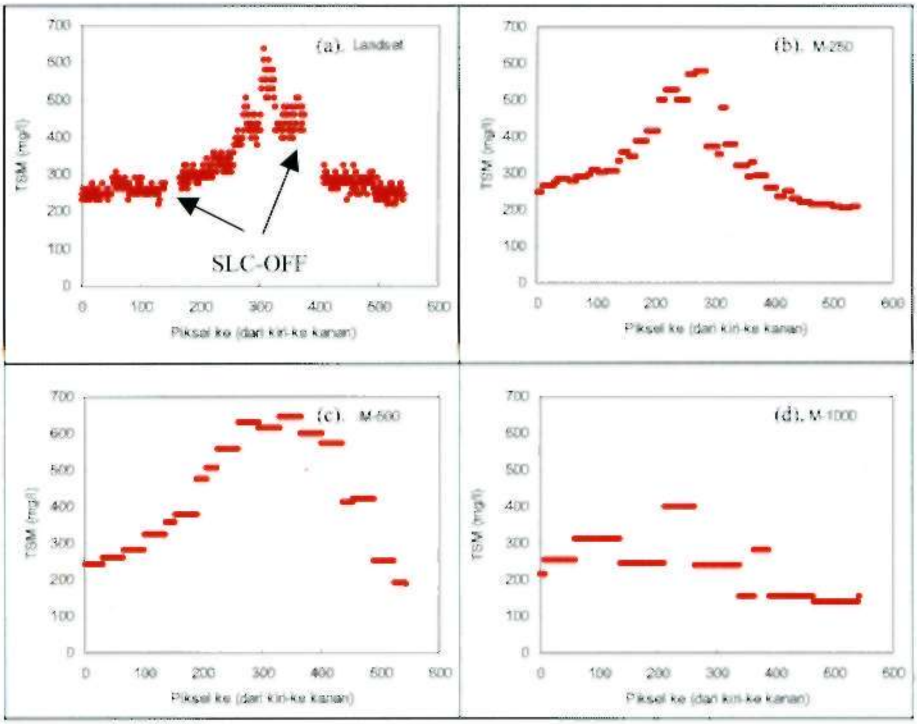


Figure 11. The distribution of TSM concentration along the transect line for Landsat (a) and MODIS 250 m (b), 500 m (c) and 1000 m (d).

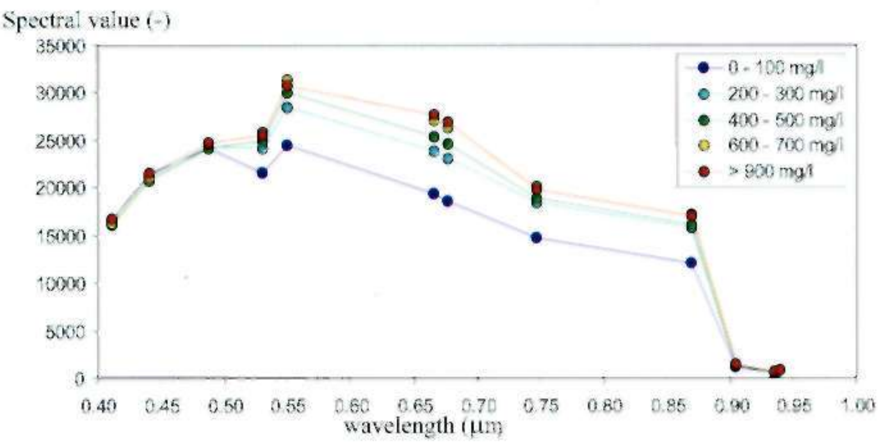


Figure 12. The spectral values of 1^ OIS data with spatial resolution 1000m for different vl concentration.

VI. Conclusion

Identification of the TSM distribution in the coastal waters with high turbidity level (Case water 3) can be examined using MODIS data with different spatial resolutions (250m, 500m, and 1000m). Model with the TSM algorithm in the form of power (X^a), with the high coefficient correlation is obtained from correlation between Landsat TSM and quantification of bandl and band2 of MODIS data with spatial resolution 250m (R^2=0.73), ratio band 4 and band 3 MODIS with spatial resolution 500m (R^2=0.754), and ratio band 13 and band 11 with spatial resolution 1000m (R^2=0.803). However, to identify the TSM distribution in coastal waters in more accurate, MODIS data with spatial resolution 250m and 500m are used

Based on MODIS hypcrspcctral band analysis with spatial resolution of 1000m, the change of TSM concentration effected significantly with the form of spectral value curve, especially for band 11-band 16 (visible green, red, and NIR).

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