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Evaluation of Total Suspended Sediment (TSS) Distribution Using ASTER, ALOS, SPOT-4 Satellite Imagery in 2005-2012

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Abstract. Lapindo mud thrown to Porong River from September 27, 2006 brought an enormous impact to the environment and surrounding communities. This will exacerbate the damage Porong ecosystems, and pollute the Madura Strait and surrounding areas (Wibisono, 2006). Disposal of sludge in large quantities and continuously to Porong also indicated sedimentation resulted in Porong River, Porong River estuary and along coastal of Surabaya-Pasuruan. This is because the material sediment transport along water flow, and the influence of geographical conditions, and the waves of the sea water. Satellite image data used in this study is the ASTER in 2005-2008, ALOS/AVNIR-2 in 2010, and SPOT-4 years 2009.2011 and 2012. In the satellite image processing, for obtain the value of is used TSS algorithm of Jing Li (2008) for ASTER satellite imagery, algorithms of Hendrawan and Asai (2008) for the ALOS satellite imagery, and algorithm of Budiman (2004) for the SPOT-4 satellite imagery. TSS value of the image processing results then performed validation / test precision using reference data TSS In-Situ to obtain linear correlation (R2). R2 value was obtained is 0.854 in 2009, 0.761 in 2011, and 0712 in 2013. That indicates that the value of TSS in the field is proportional with the TSS value in image and has a very good correlation. The results show the value of TSS in the study area ranged from 25 until more than 150 mg/L and according to the results of the analysis showed an upward trend of TSS values over time. There are several locations that indicated experiencing severe sedimentation impacts such as in Porong River, Porong River Estuary, Alo River Estuary, and the surrounding area of the estuary. According to Government Regulation Number 82 in 2001, the maximum value of TSS in the river or water is must less than 50 mg/L and so the value of TSS in the study area is very improper that if allowed to continue may damage the ecosystem in the area. Results from this study is expected to be referenced in the rehabilitation, development, and utilization of the area in the research area and coastal zone management in the future.

Keyword: TSS, Sedimentation, Satellite imagery, Linear Correlation

1. Background

Lapindo mudflow was phenomenom of hot mud spurt at drilling site of Lapindo Brantas since May 27th 2006 in Porong District, Sidoarjo Regency, East Java Province. According to [9], the volume of mudflow reaches 50,000 - 126,000 m3 per day. On September 27th, 2006, the Government approved that mudflow was dumped into Porong River which will be flown into the sea to provide additional time in effort to prepare for others alternative.

The impact of the mud disposal into Porong River against the environment and society was enormous. It will be worsening damage of ecosystem in Porong River, contaminate of Madura Strait and its surrounding [9]. Sedimentation in Porong River, Porong estuary, and along the coast of Surabaya-Pasuruan caused by mud disposal in wavelengths that can be used to measure TSS values, have good spatial resolution and multitemporal.

Parameters which can be used to measure sedimentation were TSS (Total Suspended Sediment). Remote sensing methods using satellite imagery can be solution to do research about issue of sedimentation, because this method more efficient and more effective in large-scale research. One of many kind of satellite imagery which can be used to examine TSS such as ASTER, ALOS / AVNIR-2, and SPOT-4 because it has wavelengths which can be used to measure TSS values, have good spatial resolution and multitemporal.

Based on these issue, so it necessary to do sedimentation research using TSS parameters in estuary of Porong River using ASTER, ALOS / AVNIR-2, and SPOT-4 satellite imagery to provide information about value, distribution, sedimentation potential, and recommendations for coastal area management in these areas. The results of this study were expected to be used to optimize the results of sedimentation research using satellite imagery technology and can be useful for coastal area management in the future.

2. Methodology

2.1. Study Area

Study area for this study is located in Porong River, Sidoarjo Regency, East Java, Indonesia with geographical location being on 7°10’20” south latitude - 7°36’00” south latitude and 112°34’52” east longitude - 112°54’36” east longitude.

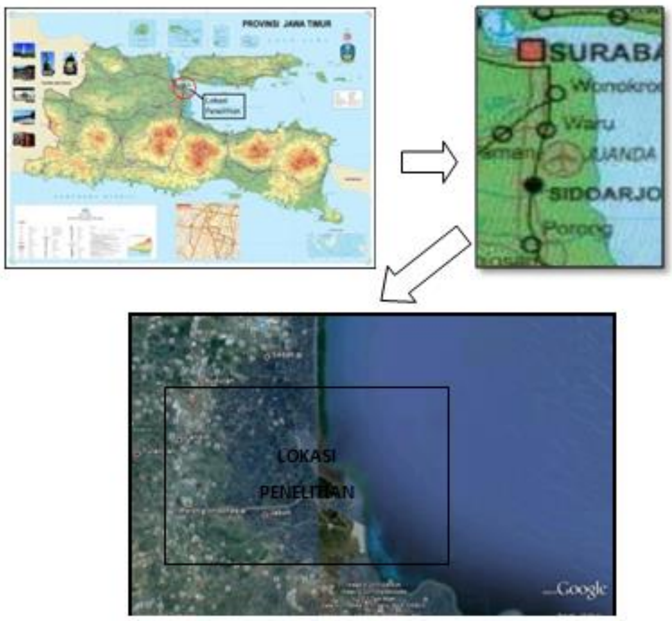

Figure 1. Study Area

2.2. Data Acquisition

ASTER Satellite Imagery Level 1B data acquired since 2005 until 2008 which have 15 meters resolution, ALOS / AVNIR-2 level 1B data acquired at 2009 which has 10 meters resolution, and SPOT-4 level 2A data acquired at 2011 which has 20 meters resolution. Geometric correction process used Landsat-7 ETM Ortho data acquired at 2000 which has 14,5 meters resolution. The use of

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satellite imagery due to ASTER, ALOS / AVNIR-2, and SPOT-4 satellite imagery suitable for the study of sedimentation and it has small aquatic areas (Kishino, 2005).

2.3. Data Processing

2.3.1. Cropping Image. Coverage area used administrative boundary of the village in some districts of Sidoarjo and Pasuruan, for coverage area to the sea used area of study as desired. In order to crop the coverage area, base data used RBI Map scale of 1: 25.000.

2.3.2. Geometric correction. The geometric platform of ASTER sensor has 10 control points which was provided with geographic coordinates reference of DEM data were obtained from GTOPO30 1997 data, so ASTER product has been corrected 3D (x, y, z) from the sensor platform and ASTER satellite imagery has a high geometric accuracy. However, there is one important step for geometric correction such as an angular rotation parameter of the sensor. Geometric accuracy of ASTER imagery reaches RMSerror <0.2 for scale of 1: 50,000. It's served as the basis that geometric correction of ASTER imagery up to the rotation only for the accuracy of mapping in this study. Whereas, geometric correction of ALOS / AVNIR-2 level IB and SPOT-4 level 2A using Landsat-7 ETM Ortho image as a reference. Geometric correction aims to reduce geometric errors by taking into account the RMS error must be less than or equal to one. Geometric correction was done by specifying GCP (Ground Control Point). GCP was performed using Landsat-7 ETM Ortho path / row: 118/065 acquisition of August 17, 2000 with a spatial resolution of 14.25 meters. In order to process of geometric correction, used polynomial method with linear interpolation and nearest neighbour resampling method. After determining GCP point then the next step is to calculate the SoF (Strength of Figure) of the GCP point distribution net.

2.3.3. Masking Image (Separation of Land and Sea). Masking process was done by looking for the range of maximum and minimum brightness values on the object. Decreasing the brightness value occurs at near infrared wavelengths about 1.4 - 2.7 µm, it is not the case in soil objects (land). In these channels the electromagnetic wave radiation does not penetrate the water body (Lillesand / Kiefer, 1997). Bands with these wavelengths produce very dark brightness values in the image display, so that can be seen the boundary between the waters and the mainland. For ASTER image, masking process using band 3. It was calculated using the following algorithm:

$$\text{if } i1<30 \text{ then } i2 \text{ else null} \quad (1)$$

2.3.4. Conversion of DN to reflectance for ASTER Imagery

The radian data (L_{rad}) were calculated using the following equation:

$$L_{rad} = (DN-1) \times \text{Unit Conversion Coefficient (UCC)} \quad (2)$$

(i.e. Abrams and Hook 1998)

The reflectance data (RTOA) were calculated using the following equation:

$$R = (pi \times L_{rad} \times d^2)/(ESUN_i \times \cos(z)) \quad (3)$$

(i.e. Abrams and Hook 1998)

Where,

Z = 90^0 - solar elevation angle (5)
ESUN = Solar Atmospheric Irradiance

The count of DN multiplier variables were calculated using the following equation:

$$R= ((DN-1) \times UCC \times pi \times d^2) / (ESUN_i \times \cos(z) \quad (4)$$
$$a = (UCC \times pi \times d^2) / (ESUN_i \times \cos(z)(7)$$

where, a is the multiplier variable (DN-1).

2.3.5. DN to Reflectance Conversion for SPOT-4 Imagery

The equations used to change the value of DN into the reflectance value are:

- Digital Number (DN) to Spectral Radiance

$$L\lambda = DN / (G\lambda * A\lambda) + B\lambda \quad (5)$$

- Spectral Radiance to Reflectance

$$\rho_p = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos \theta_s} \quad (6)$$

Where,
L = spectral radiance at aperture sensor (mWcm-2. $ster^{-1}$. μm^{-1}).
DN = Digital Number
Gλ = Gain
Aλ = Absolute Correction
Bλ = Bias
P = unitless planetary reflectance at the satellite (on a scale of 0-1).
Π = 3.141593

2.3.6. TSS algorithm

- Jing Li (2008) algorithm for ASTER imagery
  Formula Jing Li was a formula which uses Multi Band in its calculations, in this formula uses reflectance band 1 and band 2 for ASTER image. The Value of Suspended Sediment Concentration (SSC) / TSS (Li et al., 2008) using the following model:

$$X=[R_w(\lambda_{550})+R_w(\lambda_{670})]*[R_w(\lambda_{670})/R_w(\lambda_{550})] \quad (7)$$

(Han et al., 2006)

where,
Rw (λi) is the reflectance value of the precipitate with units of wavelength nm.
Rw (λ550) is suitable for detecting high reflections against chlorophyll.
Rw (λ670) is used to detect high absorption of chlorophyll.
[Rw (λ670) / Rw (λ550)] can reduce chlorophyll disorder.

Jing Li proposes the following equation:

$$Log_{10} S (mg/l) = 0.892+6.2244*X \quad (8)$$

(Li et al., 2008)

Where S is the value of sediment

$$X = [Rw\ (tm1) + Rw\ (tm2)] * [Rw\ (tm2) / Rw\ (tm1)] \quad (9)$$

Then the formula was converted to the following equation:

$$S = 10^{\cdot(0,892 + 6.2244*X)} \quad (10)$$

- Hendrawan and Asai Algorithm (2008) for ALOS / AVNIR-2 imagery
  This equation was applied for ALOS / AVNIRR-2 satellite imagery, using a combination of digital number bands 1, 2, and 3. The algorithm equations used to obtain TSS (mg/L) values are as follows:

$$TSS\ (mg/l) = -1.315*b1 + 2.371*b2 + 0.791*b3 + 9.649 \quad (11)$$

Where,
b1 = Digital Number Band 1
b2 = Digital Number Band 2
b3 = Digital Number Band 3

- Budhiman Algorithm (2004) for SPOT-4 image
  This equation was based on regression result and refers to [2] algorithm. This equation was applied for SPOT-4 satellite images, using the Reflectance band 2. The following equation:

$$TSS\ (mg/l) = 7,9038*\exp(23,942*red\ band) \quad (12)$$

Where,
Red band = reflectance band 2

2.3.7. Linear Regression and Correlation. Correlation aims to looking for relationship value between suspended sediment with reflectance band, suspended sediment of each algorithm at each image. From the three values, the regression correlation test was calculated using value of ground truth, and the algorithm with the corresponding value (R2)> 70% was obtained. Furthermore, from the strongly correlated canals a model was prepared through regression analysis, which is an analysis which allows to predict the values of non-free variable of one or more non-free variables. In this study, the sediment value was suspended as non-free variable (Y), based on the reflectance value as known free variable (X).

2.3.8. Ground truth. It's aims to determine the conditions of sedimentation in the field and the condition of waters in general. This field data was used as a basis in interpretation of satellite imagery which represents the area.

2.3.9. Accuracy Test. The accuracy test in the research was conducting the field check and the measurement of some point (sample area) chosen from each class classification. Purwadhi (2001) in Pahlevi explained that the accuracy of the results was greater than 70% so the classification results are said to have better accuracy.

2.3.10. Classification. Classification is the process of grouping pixels into a particular class. In this research, the selected classification method is to classify spectral values using the tool band threshold to ROI on the ROI tools menu. The classification results are:

1. Class 1: classification of sediment values in the range of ≤20 mg / l.
2. Class 2: classification of sediment values in the range of 25-≤50 mg / l.
3. Class 3: classification of sediment values in the range of 50-≤75 mg / l.
4. Class 4: classification of sediment values in the range of 75-≤100 mg / l.
5. Class 5: classification of sediment values in the range of 100> 125 mg / l.
6. Class 6: classification of sediment values in the range of 125> 150 mg / l.
7. Class 7: classification of sediment values in the range> 150 mg / l.

3. Result and Discussion

3.1. RMS_{Error} of Geometric Correction

RMS_{Error} of ASTER amount <0.3 pixel, SPOT amount 0.4 pixel, and ALOS amount 0.2 pixel. It can be concluded that the result has fulfilled the RMS Error value for geometric correction of image that must be <1 pixel.

3.2. Accuracy Test

The accuracy test was calculated using In-Situ data from sampling of water in field (2009) and using Water Checker Troll (2011). The linear correlation between TSS field data and TSS satellite imagery on June 11, 2009 has a value of linear correlation (R^2) amount 0.84. Whereas, the value of linear correlation (R^2) on July 23, 2011 obtained is 0.98. The closer the value of one, can be interpreted that the linear correlation is better and can be interpreted that the value of TSS in the image can describe real TSS value in field.

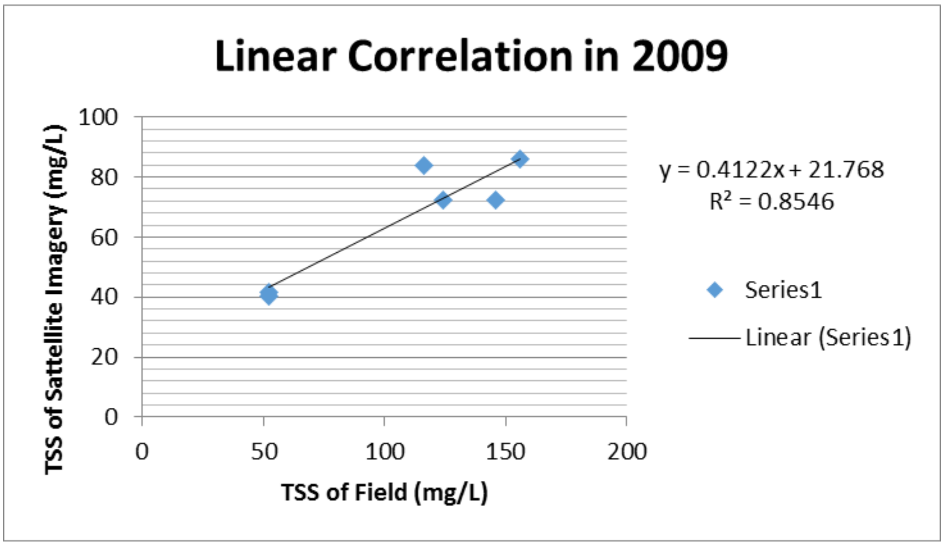

Figure 2. Linear Correlation in 2009

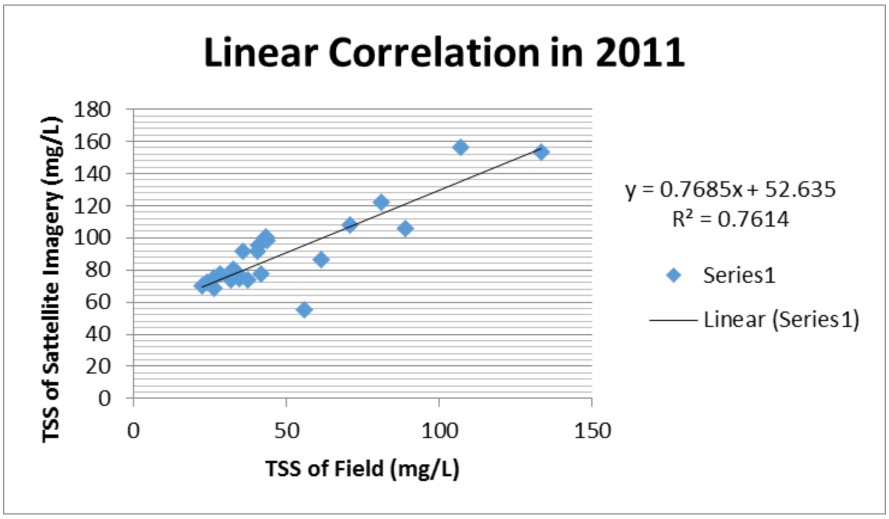

Figure 3. Linear Correlation in 2011

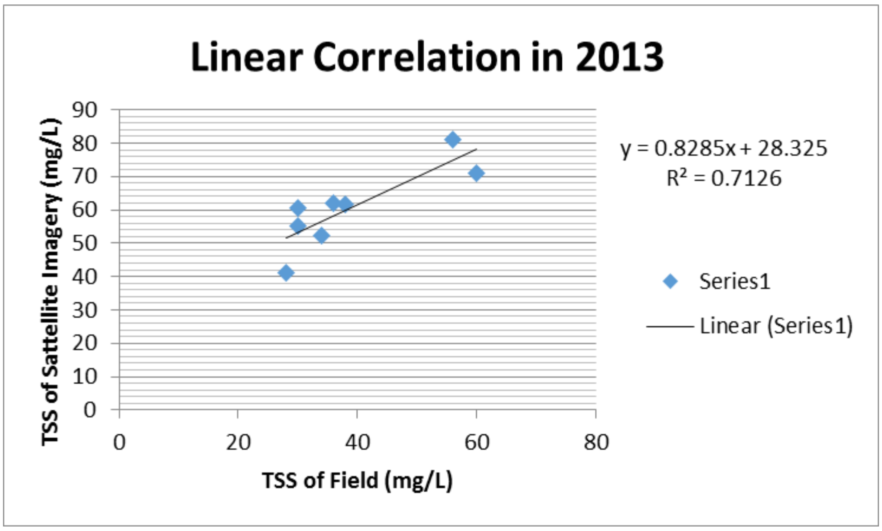

Figure 4. Linear Correlation in 2013

4. TSS Distribution Area

Table 1. TSS Distribution Area (km^2)

CLASS (mg/L)	ASTER 2005	ASTER 2006	ASTER 2007	ASTER 2008	SPOT 2009	ALOS 2010	SPOT 2011	SPOT 2012
0-25	0.000675	0	0.031725	160.107	0	15.374	0.0342	0.0477
25-50	108.149	181.703	143.868	54.073	106.73	33.445	104.222	127.093
50-75	67.043	38.936	27.302	3.472	60.538	47.923	31.459	22.254
75-100	22.532	0.3438	10.271	1.335	31.856	75.007	53.032	28.471
100-125	21.059	0.001575	8.418	0.6759	14.177	34.745	20.113	22.045
125-150	2.203	0.00045	3.808	0.245475	7.997	9.256	5.863	11.014
>150	0.0297	0.000225	10.417	0.37395	1.73	0.652292	5.314	8.496

Table 1 show us that the area distribution of TSS in each year fluctuated up and down from year to year. So, it cannot be generalized that the broad value of TSS distribution always increase or always decreases from year to year.

Table 2. TSS Distribution Area in 2005 and 2006 (km^2)

CLASS (mg/L)	ASTER 2005	ASTER 2006
0-25	0.000675	0
25-50	108.149	181.703
50-75	67.043	38.936
75-100	22.532	0.3438
100-125	21.059	0.001575
125-150	2.203	0.00045
>150	0.0297	0.000225

Table 2 show us that TSS area occurred before mudflow to Porong River. The Lapindo mud disaster occurred since early 2006 and the mud began to be flowed to Porong River since 26 September 2006. From the data can be described that the area of TSS value generally decrease.

Table 3. TSS Distribution Area in 2006 and 2007 (km^2)

CLASS (mg/L)	ASTER 2006	ASTER 2007
0-25	0	0.031725
25-50	181.703	143.868
50-75	38.936	27.302
75-100	0.3438	10.271
100-125	0.001575	8.418
125-150	0.00045	3.808
>150	0.000225	10.417

Table 3 show us that increase of TSS value before and after the disposal of Lapindo mud into Porong River. From the data can be described that the area increased TSS value.

There was a significant increase in TSS values > 75 mg / L. It indicates that the disposal of mud to Porong River influences the value of TSS in Porong River and its surroundings.

Table 4. TSS Distribution Area in 2007 and 2008 (km^2)

CLASS (mg/L)	ASTER 2007	ASTER 2008
0-25	0.031725	160.107
25-50	143.868	54.073
50-75	27.302	3.472
75-100	10.271	1.335
100-125	8.418	0.6759
125-150	3.808	0.245475
>150	10.417	0.37395

Table 4 show us about comparison area TSS of each class in 2007 and 2008. From the data can be described that the area to not so much changed.

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Table 5. TSS Distribution Area in 2008 and 2009 (km^2)

CLASS (mg/L)	ASTER 2008	SPOT 2009
0-25	160.107	0
25-50	54.073	106.73
50-75	3.472	60.538
75-100	1.335	31.856
100-125	0.6759	14.177
125-150	0.245475	7.997
>150	0.37395	1.73

Table 5 show us about comparison area TSS of each class in 2008 and 2009. From the data can be described that the all area TSS value generaly increased.

Table 6. TSS Distribution Area in 2009 and 2010 (km^2)

CLASS (mg/L)	SPOT 2009	ALOS 2010
0-25	0	15.374
25-50	106.73	33.445
50-75	60.538	47.923
75-100	31.856	75.007
100-125	14.177	34.745
125-150	7.997	9.256
>150	1.73	0.652292

Table 7. TSS Distribution Area in 2010 and 2011 (km^2)

CLASS (mg/L)	ALOS 2010	SPOT 2011
0-25	15.374	0.0342
25-50	33.445	104.222
50-75	47.923	31.459
75-100	75.007	53.032
100-125	34.745	20.113
125-150	9.256	5.863
>150	0.652292	5.314

Table 8. TSS Distribution Area in 2011 and 2012 (km^2)

CLASS (mg/L)	SPOT 2011	SPOT 2012
0-25	0.0342	0.0477
25-50	104.222	127.093
50-75	31.459	22.254
75-100	53.032	28.471
100-125	20.113	22.045
125-150	5.863	11.014
>150	5.314	8.496

Meanwhile, the comparison between the value and distribution of TSS in 2005 representing the value before the occurrence of Lapindo mudflow and TSS in 2012 representing the current condition can be seen in the following table:

Table 9. TSS Distribution Area in 2005 and 2012 (km^2)

CLASS (mg/L)	ASTER 2005	SPOT 2012
0-25	0.000675	0.0477
25-50	108.149	127.093
50-75	67.043	22.254
75-100	22.532	28.471
100-125	21.059	22.045
125-150	2.203	11.014
>150	0.0297	8.496

Table 9 show us about comparison area TSS of each class in 2005 and 2012. From the data can be described that all areas TSS value increased. The increase in terms of value and TSS distribution area indicated that the water quality is getting worse with the higher sedimentation potential. It also illustrates that Lapindo Mud Disposal event has a negative impact on the increase of TSS value in the area of research location.

5. Conclusions

The result for this research indicate that TSS value obtained from image processing has good correlation in describing field TSS value, there is a high increase of TSS value in 2005 and 2012 which indicates the influence of the Lapindo mudflow to Porong River, the value of TSS in the majority of research areas has exceeded TSS value threshold set by the Ministry of Environment <70 mg / L while in the study area it can reach > 150 mg / L which can be fatal to ecosystems in research areas such as death of aquatic biota, and severe sedimentation, there is an area indicated sedimentation will occur continuously indicated by the high value of TSS.

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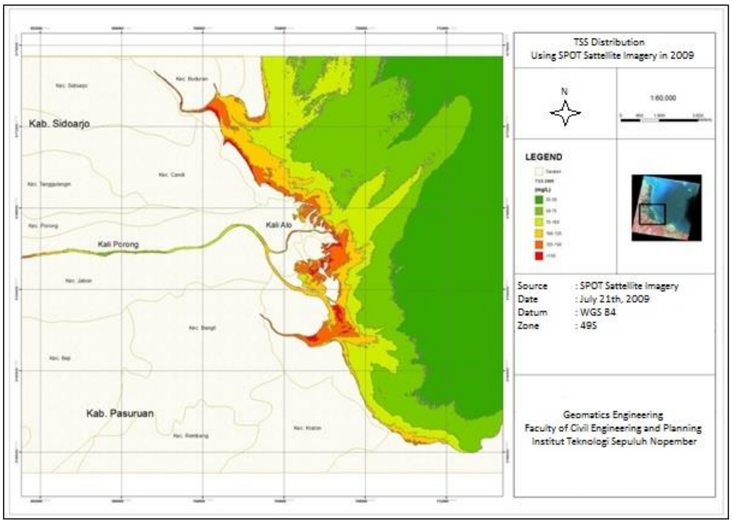
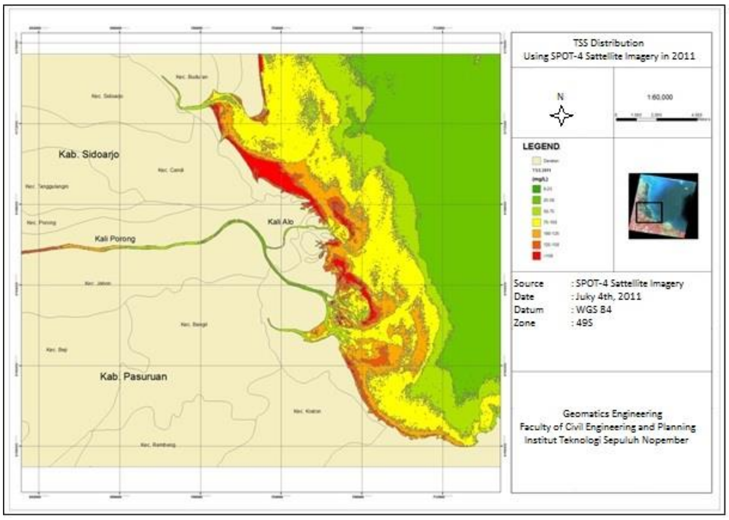
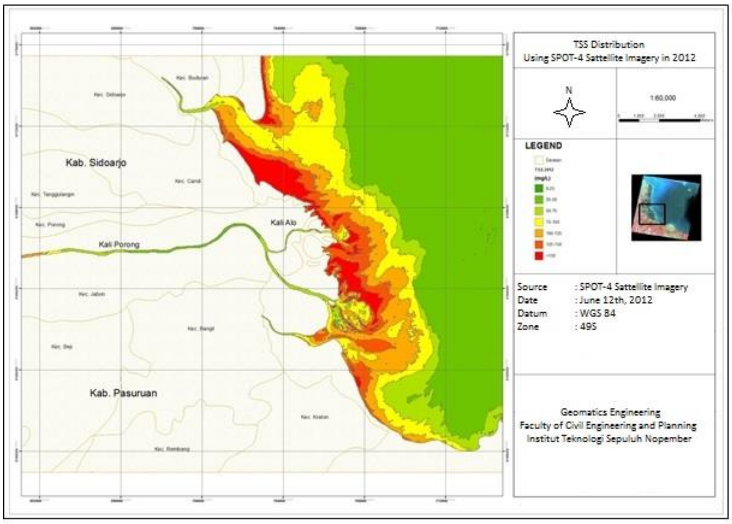
tanggal 25 Oktober, jam 18.43.

Appendix






TSS Distribution
Using SPOT-4 Sattellite Imagery in 2012
N
1:60,000
LEGEND
Kab. Sidoarjo
Kali Alo
Kali Porong
Kab. Pasuruan
Source : SPOT-4 Sattellite Imagery
Date : June 12th, 2012
Datum : WGS 84
Zone : 49S
Geomatics Engineering
Faculty of Civil Engineering and Planning
Institut Teknologi Sepuluh Nopember