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Development of Total Suspended Sediment Model using Landsat-8 OLI and In-situ Data at the Surabaya Coast, East Java, Indonesia

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Abstract The decrease of coastal-water quality in the Surabaya coastal region can be recognized from the conceentration of Total Suspended Sediment(TSS) . As a result we need a system for monitoring sediment concentration in the coastal region of Surabaya which regularly measures TSS. The principle to model and monitor TSSconcentration using remote sensing methods is by the integration of Landsat-8OLI satellites image processing using some ofTSS-models then those are analyzed for looking its suitability with TSS value direcly measured in the field (in-situ measurement). The TSS value modeled from all algorithms validated usingcorrelation analysis and linear regression . The result shows that TSS model with the highest correlation value is TSS algorithm by Budiman (2004)with r value 0.991. Hence this algorithm can be used to investigate TSS-distribution which represent the coastal water quality of Surabaya with TSS value between 75 mg/L to 125 mg/L.

Keywords: algorithm, coastal water, Landsat 8 OLI, Total Suspended Sediment (TSS), Surabaya

Abstrak *Penurunan kualitas perairan pantai dapat ditunjukkan oleh tingginya konsentrasi sedimen yang dinyatakan oleh Total Suspended Sedimen(TSS). Untuk keperluan ini diperlukan sistem monitoring dan pengukuran konsentrasi sedimen wilayah pantai Surabaya secara spasial dan non spasial, dimana pengukuran TSS dapat dilakukan secara regular dengan ketelitian yang baik. Prinsip monitoring konsentrasi TSS dengan metode penginderaan jauh adalah memproses citra dari satelit Landsat 8OLI dengan menggunakan beberapa model TSS, kemudian dilihat kesesuaiannya konsentrasi TSS yang diukur langsung di lapangan (pengukuran insitu).Penelitian ini menggunakan empat algoritma TSS untuk mendapatkan konsentrasi TSS. Nilai konsentrasi TSS dari semua algortima diuji dengan data in-situ menggunakan analisis regresi linier. Hasil menunjukkan bahwa algoritma Budiman mempunyai nilai korelasi yang paling tinggi(r=0,991).Algoritma tersebut dapat digunakan untuk melihat distribusi TSS yang merupakan indikator kualitas perairan pantai Surabaya dengan rentang nilai konsentrasi 75 mg/l sampai dengan 125 mg/l.*

Kata kunci: *algoritma, Landsat 8 OLI, Total Suspended Sediment (TSS), perairan pantai, Surabaya*

1.Introduction

Coastal areas often change in their function , the area which should be the conservation area or coastal protection, forests , as well as water catchment areas and mangrove forest habitat have been transformed into large scale residential area, industrial area, warehousing and others that have negative impacts on that region. Several cases of coastal reclamation area can be seen in coastal areas of Jakarta, as in the spatial plan of the city, the northern coastal region of Jakarta is designated as protected forest or mangrove forests, but in fact that region has been developed to be come residential area. As a result this triggers flooding in the wider regions. Form example,reclamation is a necessity for the development of the capital Jakarta, that aims to expand the area used for economic activities.

Likewise in the case of the Surabaya east coast region, the reclamation was influenced by several factors for instance the demand of residential areas , factories and so on, as well as due to the sedimentation in the river estuary which resulted in the emergence of 'new land'. The impact of the reclamation both technically (backfilling) or natural (newland) certainly have impacts either positively or negatively [Hariyanto,2014].

Monitoring the condition of the coast through TSS value change using Landsat-8 OLI (Operational Land Imager) satellite remote sensing in the Surabayaeast coast area is necessary since there are some important things to be noted as a result of the reclamation either technically or naturally (new land). The effects of the reclamation are coastline changes, social issues, population and others. Furthermore we need the update of TSS data which is necessary to determine operational policy and technical guidance for the government, public and private sector in the utilization of coastal region from occurring environmental changes

The utilization of TSS remote sensing models in the previous study was performed by Budiman [2004], Nurandani [2013] , Lestari [2009], and Rodriguez and Gilbes [2009]. Initial hypothesis is applied to obtain the highest correlation and best-fit linear regression equation

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of the TSS distribution to represent the condition of Surabaya coastal-water with 15 in-situ data sample.The TSS model which has correlation value close to 1 will be used as the basis for analyzing coastal water condition

The aims of this research are retrieveand evaluate TSS concentration distribution using four algorithms of TSS in Surabaya east coast from Landsat-8 OLI image. Evaluate TSS correlation result retrieved from four algorithms against in-situ data using correlation value (r) and linier regression analysis.The best result will be used as the basis to explains the condition of Surabaya east coast

2.The Methods

Research location is in the East Coast of Surabayawhich has a center coordinate of 7°15'20" South and 112°49'50" East (Figure 1). The Sea region of Surabaya is divided into two zones, the first zone is the strait and located in the northern part while the second zone is the sea zones located in the eastern part. Both zones have different sea level characteristics caused by the ocean currents. Madura Strait is a narrow strait which connects the Java and Madura island. Java sea (southern part of Madura) in average has strong current which is 0.5 m and 0.6 m/s at the surface and at the bottom of strait respectively. Tidal conditions on the north coast of Surabaya is Semi-Diurnal with the highest tide (HHWS) and the lowest tide (LLWS) differences is 3.10 m. Meanwhile, the sea level condition on the east coast of Surabaya has the characteristics of Semi Diurnal (two tide per day) with the highest tide (HHWS) and the lowest tide (LLWS)differences of 2.80 m with strong currents 0.4 m/s on the surface and 0.48 m/s at the bottom of the sea. Due to the sea level conditions in the eastern part of Surabaya, the occurrence of sedimentation is more likely compared to the northern part.

The spectral characteristics of Landsat 8 OLI is provided in Table 1. Landsat-8 OLI image used in this study was acquired on March 3, 2014 with the number of pat-119 and row- 065, the spatial resolution is 30mx30m. Image-to-image registration is the matching of one image to another so the same geographic area is positioned coincident with respect to the other. This type of geometric correction is used when it is not necessary to have each pixel assigned a unique x, y coordinate in a map projection [Baboo, 2011] (Figure 2) In order toget :

$$\begin{pmatrix} x \\ y \end{pmatrix} = T \begin{pmatrix} u \\ v \end{pmatrix} \quad (1)$$

Every step involved in the imaging process has to be known, i.e., we need to know the inverse process of geometric transformation.

$$\begin{pmatrix} u \\ v \end{pmatrix} = T^{-1} \begin{pmatrix} x \\ y \end{pmatrix} \quad (2)$$

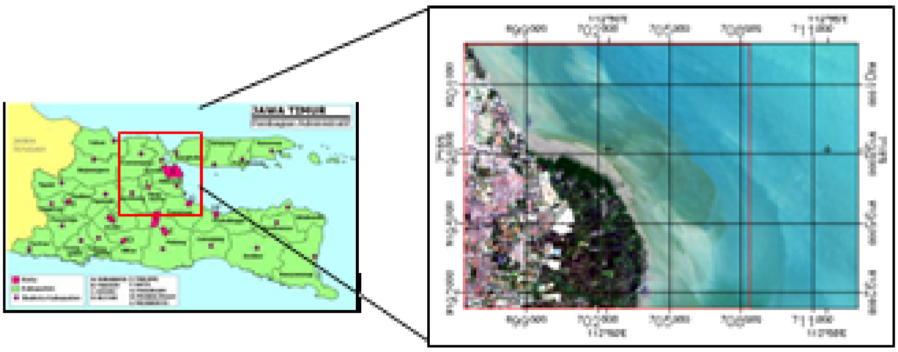

Figure 1. Research location, Surabaya east coast.
(Source: East Jawa Administration Map and Landsat 8 OLI)

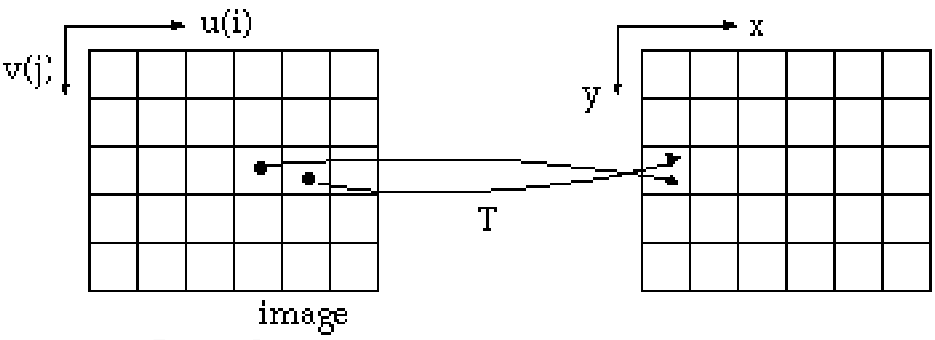

Figure 2. Image to image registration geometric correction.
(Source: http://nature.berkeley.edu/~penggong/textbook/chapter4/html/sect44.htm)

Table 1. Landsat-8 (OLI) spectral band [Edgardh, 2013]

Band	Wavelength (μm)	Resolution (m)
B1-Visible (Aerosol)	0.43 - 0.45	30
B2-Visible	0.45 - 0.51	30
B3-Visible	0.45 - 0.51	30
B4-NIR	0.53 - 0.59	30
B5-NIR	0.64 - 0.67	30
B6-SWIR1	0.85 - 0.88	30
B7-SWIR2	1.57 - 1.65	30
B8-PAN	2.11 - 2.29	15
B9-Cirrus	0.50 - 0.68	30
B10-TIRS1	1.36 - 1.38	100
B11-TIRS2	10.60	100
	11.19	
	11.50 -	
	12.51	

This is a complex and time consuming process. However, there is a simpler and widely-used alternative, the polynomial approximation.

$$u = \sum_{p=0}^{n} \sum_{q=0}^{n} a_{pq} x^p \bullet y^q \quad (3)$$

$$v = \sum_{p=0}^{n} \sum_{q=0}^{n} b_{pq} x^p \bullet y^q \quad (4)$$

Coefficients a's and b's are determined by using Ground Control Points (GCPs). For example, we can use very low order polynomials such as the affine transformation.

$$u = ax + b\Delta y + c \quad (5)$$

$$v = dx + e\Delta y + f \quad (6)$$

A minimum of three GCPs will enable us to determine the coefficients in the above equations.Therefore, we did not need to use the transformation matrix T. However, in order to make our coefficients representative of the whole transformed image, we have to make sure that our GCPs are well distributed across the image [Camper, 2011]The distance between the input location of the GCP and the retransformed coordinates of the same GCP is called the Root Mean Square (RMS) error. This is calculated in the rectification formula as follows (see Table 2 for the result)

$$R_x = \sqrt{\frac{1}{n} \sum_{i=1}^{n} XR_i^2} \quad (7)$$

$$R_y = \sqrt{\frac{1}{n} \sum_{i=1}^{n} YR_i^2} \quad (8)$$

$$T = \sqrt{R_x^2 + R_y^2} \;\; or \;\; R_x = \sqrt{\frac{1}{n} \sum_{i=1}^{n} XR_i^2 + YR_i^2} \quad (9)$$

Where :

Rx = X RMS Error
Ry = Y RMS Error
T = Total RMS Error
n = the number of GCPs
i = GCP number
XRi = the X residual for GCPi
YRi = the Y residual for GCPi

TSS in-situ Data.

In-situ data came from water samples on the East Coast of Surabaya when were taken at March 24, 2014 by the random sampling method as much as 15 points in the study site at a depth of 0.5 - 2 m .Furthermore water samples were processed using Gravimetry method in Water Laboratory of Environmental Engineering - ITS to obtain the value of TSS .

Radiometric Correction

Landsat 8 OLI band data can also be converted to Top-of-Atmospheric(TOA) planetary reflectance using reflectance rescaling coefficients provided in the product metadata file (MTL file). The following equation is used to convert DN values to TOA reflectance for Landsat 8 OLI data:

$$\rho\lambda' = M\rho Qcal + A\rho \quad (10)$$

where:

ρλ' = TOA planetary reflectance, with no correction

Table 2. The result of geometric correction (pixel).

GCP	Base X	Base Y	Warp X	Warp Y	Predict X	Predict Y	Error X	Error Y	RMS
1	3041.75	2366.25	2766.00	4845.50	2765.867	4845.580	-0.1334	0.0796	0.155
2	2662.50	2554.25	2385.75	5035.50	2385.758	5035.491	0.0082	-0.0091	0.012
3	2713.00	2330.00	2436.50	4810.25	2436.449	4810.284	-0.0509	0.0337	0.061
4	2664.24	2779.00	2367.50	5261.00	2367.440	5261.039	-0.0603	0.0387	0.072
5	3140.50	2813.50	2863.50	5295.25	2863.424	5295.296	-0.0758	0.0457	0.089
6	2943.50	2543.75	2666.75	5024.50	2667.060	5024.312	0.3096	-0.1885	0.362
7	3160.75	2536.75	2884.56	5016.77	2884.563	5016.770	0.0026	-0.0001	0.003
				RMS Error Total					0.157

Table 3. TSS insitu laboratory data measured using Gravimetry method

No. Point	TSS (mg/L)	X (m)	Y (m)
1	44	704337	9193046
2	29	702649	9200424
3	62	704384	9195010
4	29	704114	9199646
5	94	703323	9196945
6	36	703355	9198889
7	30	705283	9198413
8	34	699994	9200567
9	47	701568	9199269
10	40	701357	9201597
11	24	706292	9192318
12	28	706088	9194229
13	35	699700	9202008
14	76	706385	9195644
15	60	706024	9197009

for solar angle
Mρ= Band-specific multiplicative rescaling factor taken from the image metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)
Aρ= Band-specific additive rescaling factor taken from the image metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)
Qcal= DN

To obtainTOA reflectance value with a correction for the sun angle, the following formula was used

$$\rho\lambda = \frac{\rho\lambda'}{\cos(\theta_{SZ})} = \frac{\rho\lambda'}{\sin(\theta_{SE})} \quad (11)$$

where:

ρλ = TOA planetary reflectance
θSE = Local sun elevation angle. The value of scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION)
θSZ = Local solar zenith angle; θSZ = 90° - θSE

Some models of TSS algorithm used in this study can be seen in the following explanation

3. Result and discussion.

Budhiman [2004] method is based on bio optical modeling. The forward water analysis comprised the laboratory measurements of water quality (TSS and Chlorophyll) and Inherent Optical Properties (IOPs) to derive Specific Inherent Optical properties (SIOPs). SIOPs of water (TSM, Chlorophyll and CDOM), coefficient f and B were used to developed R(0-) model. The inverse atmosphere analysis encompassed several image pre-processing procedures (i.e geometric correction, atmospheric correction, air-water interface correction). The last step is the inverse water analysis, which comprised the development of algorithm and image processing to develop TSS concentration maps. The results indicate that red band of satellite sensor is sensitive to detect higher TSS concentration. Green band is sensitive to detect the lower TSS concentration. For Mahakam Delta, red band algorithm was used to derive TSS map, since higher TSS concentration occurred in the delta.The result can be seen in Figure 3 and the formula is as follow,

$$TSS\ (mg/l) = 7.9038 * exp\,(23.942 * x) \quad (12)$$

where :
x= reflextance of Band 3 (red)

TSS Algorithm 2 : Nurandani [2013]

Based on Nurandani [2013], who observed and measured TSS in Rawa Pening, the results of data processing , empirical matching algorithm for the concentration of TSS is a logarithmic regression equation model using the ratio between band 1 (blue) with band 2 (green) of Landsat 7 ETM+.Therefore it changes into band 2 (blue) and band 3 (green) on Landsat-8 OLI respectively. The equation is as follow:

$$TSS\ (mg/l) = 368.7 * ln(x) + 31.52 \quad (13)$$

where :
x = Reflectance Ratio betwen band 2 and band 3

The majority of TSS value is between 75-100 mg/L, which covers almost all of the study area, while the value of TSS between 50-75 mg/L is distributed in Madura Strait.Using this algorithm , there is only limited area with TSS value between 25-50 mg/L.The TSS map can be seen in Figure 4.

TSS algorithm 3: Lestari [2009]

Based on Lestari [2009], the best empirical model to predict the concentration of TSS is the 3rd degree polynomial regression model, both for the dry and rainy seasons. The model is created by the relationship between the chromaticity transformation reflectance values of blue band with TSS concentration in-situ data. Here is the formula:

$$TSS(mg/l)=24197x^3-22050x^2+6813x-644.98 \quad (14)$$

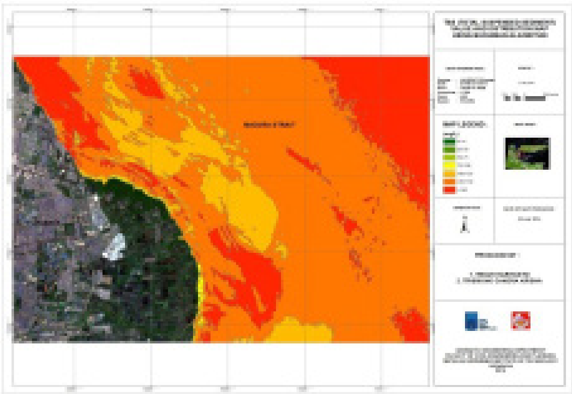

Figure 3. TSS map distribution using Budhiman [2004] algorithm.

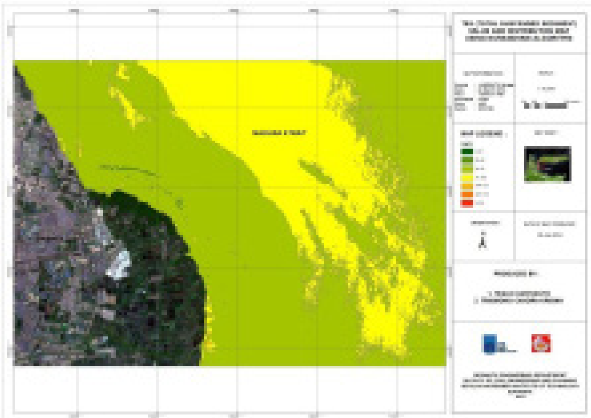

Figure 4. TSS map distribution using Nurandhani [2013] algorithm.

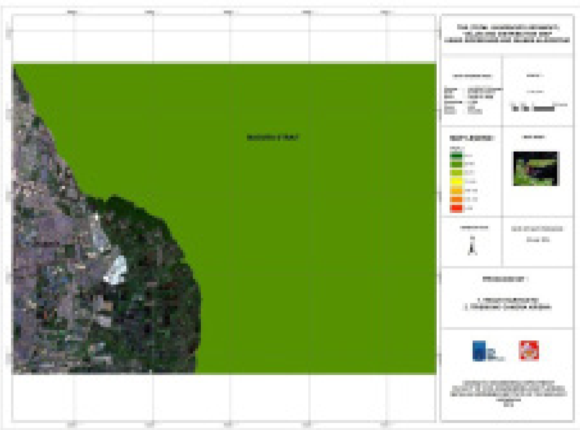

Figure 5. TSS distribution map using Lestari [2009] algorithm

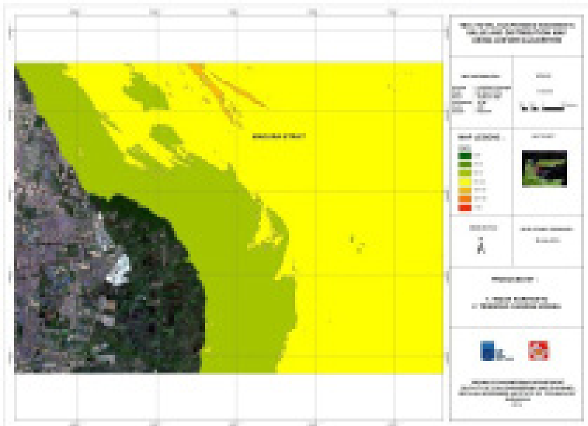

Figure 6. TSS distribusion map using Rodriguez and Gilbes [2009] algorithm

Table 4. TSS and insitu data value

X	Y	Insitu	TSS 1	TSS 2	TSS 3	TSS 4
704337	9193046	44	134.5768	68.26647	37.70394	76.03919
702649	9200424	29	123.707	56.95261	36.65344	63.01086
704384	9195010	62	151.1878	69.24554	40.01199	77.60974
704114	9199646	29	120.8465	56.90761	36.51542	62.26074
703323	9196945	94	174.1747	72.03088	40.62543	79.58472
703355	9198889	36	125.9703	65.10379	37.51991	73.6571
705283	9198413	30	124.2871	61.22649	36.90648	66.31433
699994	9200567	34	124.724	61.58656	37.31288	71.10242
701568	9199269	47	139.628	68.74805	38.11801	76.21643
701357	9201597	40	130.6984	67.49869	37.55825	74.63062
706292	9192318	24	115.1877	55.3726	35.8253	60.07251
706088	9194229	28	115.39	55.79576	35.83297	61.91773
699700	9202008	35	125.6025	64.78537	37.45857	71.74793
706385	9195644	76	161.5173	70.73078	40.28037	79.48254
706024	9197009	60	143.8556	69.20729	38.83112	76.26843

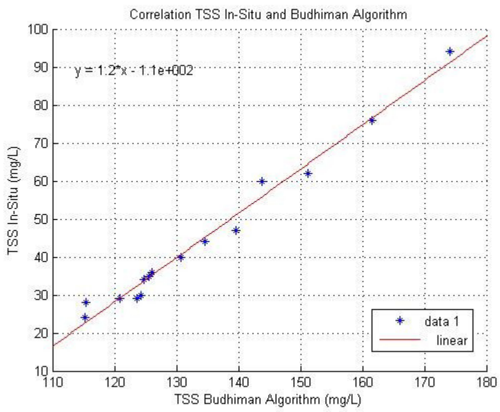

Figure 7. Linear regression analysis between TSS insitu over TSS retrieved using Budhiman [2004] algorithm.

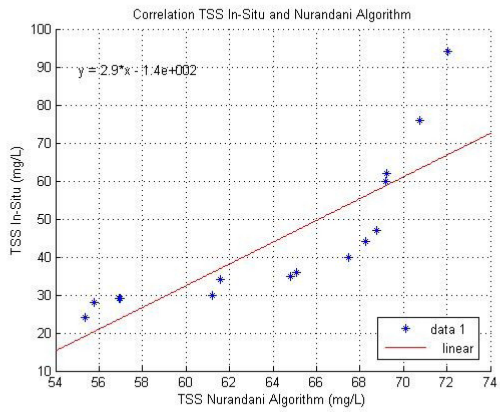

Figure 8. Linear regression between TSS insitu over TSS modeled using nurandani [2013] algorithm.

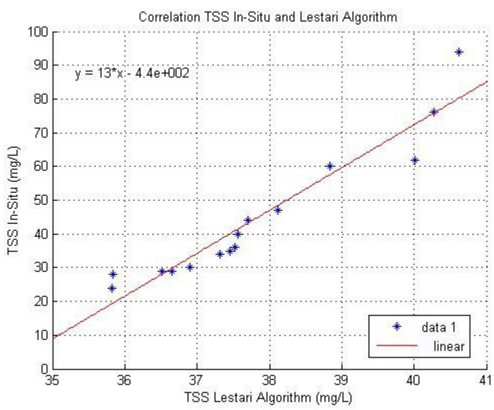

Figure 9. Linear regression between TSS insitu over TSS retrieved using Lestari [2009] algorithm.

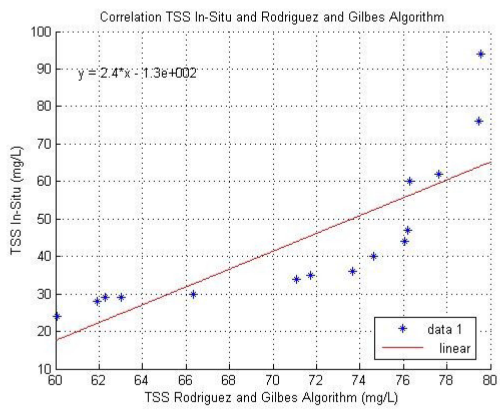

Figure 10. Linear regression between TSS insitu over TSS retrieved using Rodriguey and Gilbes [2009] algorithm.

where :
x= reflectance of blue band l chromaticity. according to Wouthuyzen et al. (2008) in Lestari (2009), blue band chromaticity is : (band 2 / (band 2+band 3+band 4)

TSS distribution obtained usingLestarialgorithm can be seen in fig.10 where the TSS value appears in the range of 25-50 mg/L TSS algorithm 4 : Rodriguez and Gilbes (2009). The result of Rodriguez and Gilbes (2009) algorithm shown in Figure 6 produced 3 broadest TSS value ranges.TSS range of 75-100 mg/L which covers the largest area, while the next largest TSS value is between 50-75 mg/L and the smallest area of TSS value is between 100-125 mg/L .The formula is as follow :

$$TSS=602.63*(05157*x-0.0089+3.1481 \quad (15)$$

where :
x = reflectance band 2

Figure 7 explain the regression analysis between the TSS in-situ data over the TSS retrieved using Budhiman [2004] algorithm, where it has a good density at the sample number 3, 6 and 7 as well as at 8 and 9. Therefore, it has a high value of R2 = 0.982, while the correlation value (r) is 0.991. Figure 8 explains regression analysis between the TSS insitu data over TSS retrieved using Nurandani [2013] algorithm, where the highest density is at the sample number 11. From the calculation it has R2 of 0.684 and r of 0.827. Figure 9 explains the regression analysis between TSS insitu data with TSS modeled using Lestari [2009] algorithm, where good density appeared at sample number 3, 4, 10 , 11 and 13.The value of R2 is 0.915 while the value of r is 0.957.

Figure 10 explains the regression analysis between the TSS in-situ data with TSS modeled using Rodriguez and Gilbes [2009] algorithm, where the relationship is quite poor R2 of 0.652 and r of 0.807. Based on analysis test for all TSS models using linear regression method, the maximum r value was obtained from Budiman algorithm with r = 0.991. Hence the water condition in the eastern coast of Surabaya based on the results of Budiman's [2004] TSS algorithm has the biggest range of TSS value between 100-125 mg/L.The value of 125 mg/L are located in the edge of the coastline indicating the new land formation as a result of the sedimentation process .

4.Conclusion

The use of fourt TSS algorithms applied to Landsat-8 OLI result in the TSS distribution vary from 40 mg/L up to 150 mg/L, where the highest variety of TSS value was obtained using Budiman [2004] algorithm, whereas the lowest TSS value is obtained using Lestari [2009)] Nurandani [2013] and Rodriguez and Gilbes [2009] algorithms produced almost similar TSS valuesUsing four TSS algorithms above, model with the highest correlation with TSS Budhiman [2004] algorithm with r value 0f 0.991. The lowest correlation value was obtained from Rodriguez and Gilbes [2009] algorithm. The concentration of TSS in the east coast of Surabaya based on Budiman algorithm which has the largest value of 125 mg/L, are distributed on the edge of the coastline, and thus increasing sedimentation process.

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