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THE USE OF SENTINEL-2 IMAGERY FOR TOTAL SUSPENDED SOLIDS (TSS) ESTIMATION IN PORONG RIVER, SIDOARJO

Filsa Bioresita[1,2], Cherie Bhekti Pribadi[2], Hana Sugiastu Firdaus[3], Teguh Hariyanto[2], Anne Puissant[1]
[1]Laboratoire Image, Ville, Environnement—LIVE/CNRS UMR 7362, Department of Geography, University of Strasbourg, 3 rue de l'Argonne, 67000 Strasbourg, France,
e-mail: filsa.bioresita@etu.unistra.fr or filsa.bioresita@gmail.com
[2]Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia
[3]Department of Geodesy Engineering, Diponegoro University, Jl. Prof Soedarto, SH, Tembalang, Semarang-75123Telp./Faks: (024) 736834

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ABSTRACT

Sidoarjo mud disaster is an occurrence of hot mud bursts at drilling location of Lapindo Brantas Inc., Sidoarjo, Indonesia since 29th May 2006. In order to overcome the continuous mud flow, Indonesian government built embankment around the center of the mudflow. They also throw mud materials into the Porong River. The large and continuous disposal of mud material leads to sedimentation in Porong River. Remote sensing method with satellite imagery can be a solution to find out how much sedimentation occurred in Porong River as a result of mud's disposal. Total Suspended Solid (TSS) calculation from satellite image can be indicator of sedimentation distribution.

In previous studies, TSS distribution has been observed from Landsat-7 and Landsat 8 data. Nowadays, with ability of Sentinel-2 which has higher spatial resolution (10 m) and higher revisit time (up to 6 days), optimization of TSS distribution in Porong river can be done. Thus the objective of this research is analysis of Sentinel-2 imagery application to estimate TSS in Porong River. Result showed good correlation between in-situ data and TSS estimation from Sentinel-2 with value 0.72.

Keywords : Sentinel-2, TSS, Porong River.

1. INTRODUCTION

Sidoarjo mud flow disaster caused many loss and harm for people in Sidoarjo. As an action to overcome the continuous mud flow, mud materials are thrown into Porong River. The large and continuous disposal of sludge material can leads to sedimentation in not only along Porong River, but also estuary of that river which located in Madura Strait (Walhi, 2016).

Sedimentation can caused degradation of water quality and thus caused environmental pollution. One of parameters to estimate water quality is TSS (Total Suspended Solids). TSS have some effects on human activities and aquatic ecosystems. It concern the modification of river morphology due to sedimentation and erosion, resulting bed sediment washout, sandbar moves, mudflat, or silting-up (Gernez, *et al.*, 2015).

TSS can also have an effect on changes in light attenuation and primary production, oxygen saturation, alteration of fish nursery function, biogeochemical cycles, transport of attached pollutants and modification of nutrients pathways (Gernez, *et al.*, 2015). High concentration of TSS values can decrease photosynthesis activity and increase the heat on the water surfaces, thus reduce the oxygen released by the aquatic plants and can lead to the death of fish and other aquatic animals (Wirasatriya, 2011).

Regarding estuary of Porong River, TSS concentration can be characterized by a high degree of variability due to the concomitant intrusion of marine waters and freshwater discharge. It can produce physical and chemical mixed processes such as sediments deposition and resuspension during tidal cycles, turbulence-induced particle accumulation and flocculation (Gernez, *et al.*, 2015). In order to calculate an accurate TSS variation, high spatial and high temporal measurement is needed.

Remote sensing data can become a solution for TSS monitoring. It can provide large area of observation and fast to accumulate the data. Nowadays, with the availability of Sentinel-2 with high spatial resolution (up to 10 meters) and high revisit time (up to 5 days), it will be easier to observe TSS concentration.

In previous research, people have investigated TSS concentration using Landsat-7 and Landsat 8 satellite images which resulted satisfactory results. Researchers also have been using MODIS imagery to detect TSS concentration (Karondia and Jaelani, 2015; Gumeidhidta, 2016; Budianto and Hariyanto, 2017). Given the results obtained from the previous researches it is necessary to continue the research by analyzing TSS concentration using Sentinel-2 imagery which has higher spatial and temporal resolution than previous imagery data. The objective of this research thus is analysis of Sentinel-2 imagery to estimate TSS in Porong River.

2. LITTERATURE REVIEW

Total Suspended Solid (TSS) is a solid (sand, silt and clay) or suspended particles in water and may be a biotic components such as phytoplankton, zooplankton, bacteria, fungi, or abiotic components such as detritus and inorganic particles. It is one of water quality parameters used to assess the quality of a specimen of any type of water or water body (Ainy *et al.*, 2011).

Some methods based on algorithm are developed in order to estimate TSS values from passive remote sensing data. Those algorithms are normally used for MODIS or Landsat imagery (Karondia and Jaelani, 2015; Gumeidhidta, 2016). There are only a few research about TSS estimation using Sentinel-2 images.

One of the algorithms which commonly give good result to detect TSS concentration is algorithm from Laili (2015). This algorithm is developed for Landsat imagery in remote sensing reflectance format. Comparison of band 2 (blue) and band 4 (red) are used as the main role play in this algorithm.

$$\text{TSS}\left({}^{mg}/_{l}\right) = 31.420\left(\frac{logRrs(\lambda 2)}{logRrs(\lambda 4)}\right) - 12.719 \quad (1)$$

Rrs (λ2): remote sensing reflectance of band 2
Rrs (λ4): remote sensing reflectance of band 4

In Sentinel-2 image, band 2 (blue) is sensitive to vegetation aerosol scattering and useful for bathymetric mapping, while band 4 (red) has a purpose to detect maximum chlorophyll absorption (EOX, 2018). Thus, in this study, we also tried to apply the algorithm to band 2 and band 4 of Sentinel-2 image. Following algorithm of Laili (2015), comparison of those bands will be performed. However, the algorithm will applied directly to BoA format (Bottom of Atmosphere). BoA is not changed to remote sensing reflectance format. Therefore, the algorithm will become into the equation 2 below.

$$\text{TSS}\left({}^{mg}/_{l}\right) = 31.420\left(\frac{logBoA(b2)}{logBoA(b4)}\right) - 12.719 \quad (2)$$

BoA (b2): BOA reflectance of band 2
BoA (b4): BOA reflectance of band 4

3. RESEARCH METHODOLOGY

3.1 Study Area and Data

Study area in this research is surface waters areas which passed by Sidoarjo mud disposal included estuary of Porong River and Java Sea in Sidoarjo Regency, East Java. Location of study area can be seen in Figure 1 below.

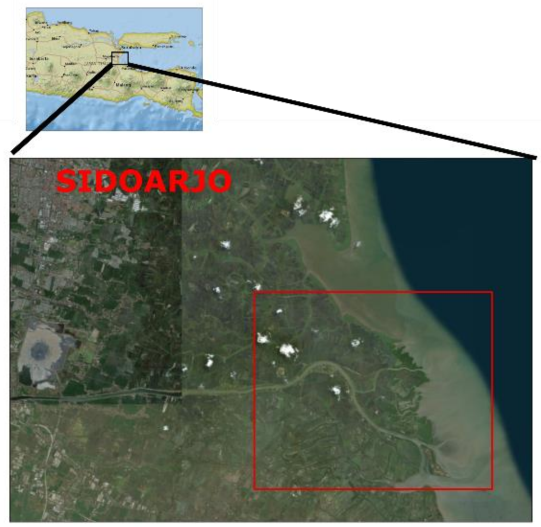


Figure 1. Study area for TSS estimation

Sentinel-2 has 13 spectral bands with four bands at 10 meters, six bands at 20 meters and three bands at 60 meters spatial resolution. Sentinel-2 provide a revisit time of 5 days at the equator in cloud-free conditions. Therefore, Sentinel-2 has high spatial and temporal resolution which can be useful for TSS monitoring.

Figure 2. Sentinel-2 images in natural color (band 4, 3, and 2)

One image of Sentinel-2 acquired on 12th January 2016 is used for this study. That image is obtained from THEIA website (CNES, 2018) in BoA format. Image has been corrected atmospherically and pixels values represented reflectance image in the bottom of atmosphere. Visualization of Sentinel-1 image is presented in Figure 2 and Figure 3. Figure 2 visualize combination of band 4, 3, and 2 for natural color image, while Figure 3 refer to false color image with band combination of 8, 4, and 3. As for reference data, nine points of in situ data obtained in 20th Avril

2016 are used to assess our results (Budianto and Hariyanto, 2017).

Figure 3. Sentinel-2 images in false color infrared (band 8, 4, and 3)

3.2 Method

As explained in literature review, in this study, algorithm from Laili (2015) will be applied to Sentinel-2 image to extract TSS values. Sentinel-2 band 2 and band 4 with spatial resolution 10 meters will be used. Band 2 and band 4 of Sentinel-2 have almost the same wavelength with band 2 and band 4 of Landsat-8 image (see Table 1). They also represent blue and red band in Sentinel-2 data. In order to adapt the algorithm with Sentinel-2 imagery, equation (2) as explained in previous section will be used.

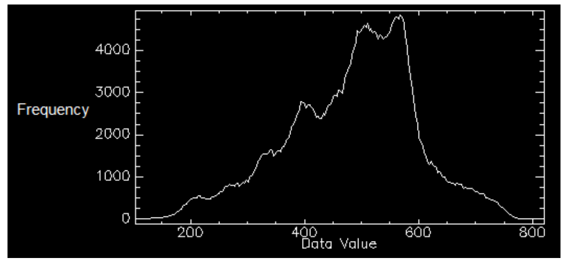
Table 1. The nominal band centers of some bands from Sentinel-2. Also included are the corresponding characteristics of Landsat-8 for comparisons (Pahlevan *et al*, 2017).

Images	***Nominal band centers (nm)***						
	B1	**B2**	**B3**	**B4**	**B9**	**B10**	**B11**
Landsat-8	443	482	561	655	865	1609	2201
Sentinel-2	444	497	560	664	865	1613	2200

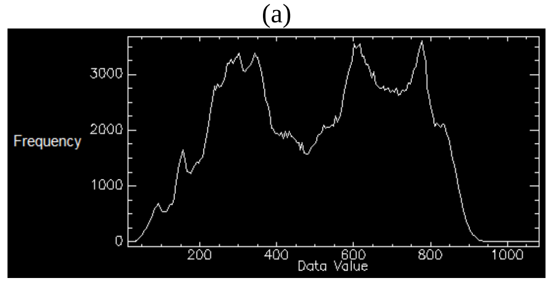
Before algorithm applied on those bands, land mask was performed in order to focus on sea as waters areas. Subsetting images in study area was done to limit image analysis. If land mask and subsetting were done, images are ready to become input data for algorithm.

4. RESULTS AND DISCUSSIONS

Band 2 and band 4 used for the algorithm have different range of distribution in BoA reflectance. In the study area, histogram distribution of BoA values from each band are extracted in order to know their distribution related to coastal areas. Band 2 has minimum pixel value about 103 and maximum pixel value about 821 with mean value 485.890. Band 4 has wider range values from 12 to 1084 with mean value about 512.262. Those histogram distribution can be seen in Figure 4 below.



(a)



(b)

Figure 4. Histogram distribution of BoA from (a) Band 2 and (b) Band 4 in study area.

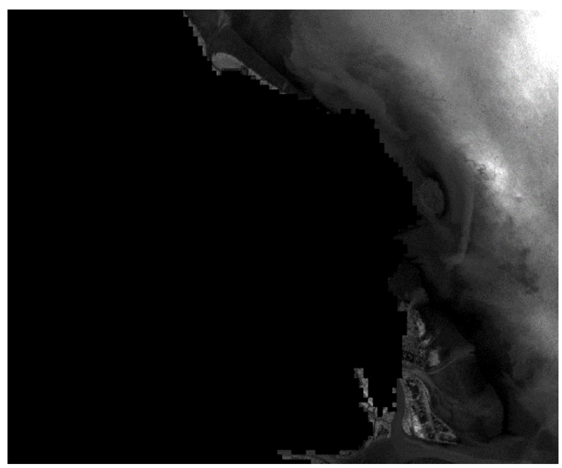


Figure 5. TSS resulted image from algorithm.

Figure 5 showed image result after applied algorithm. Black areas in the left side of image is masked land and the other areas coastal areas. Those gray values areas in the coastal side represented TSS distribution. Each pixel of those areas contains TSS values. Histogram distribution of resulted image can be seen in Figure 6. The minimum value about 14.8 and maximum pixel value about 55.9 with mean value about 19 mg/l.

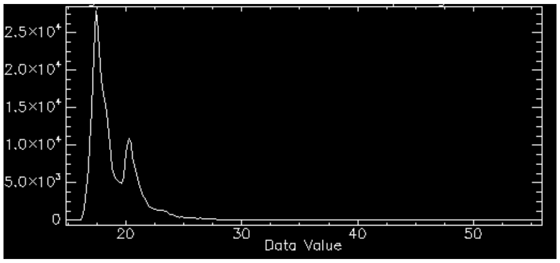


Figure 6. Histogram distribution of TSS image.

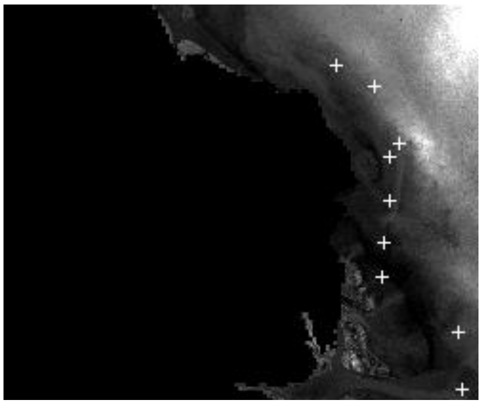


Figure 7. Validation points distribution in TSS image.

Table 2. TSS resulted from Sentinel-2 image compared with in situ data in nine points.

Coordinates		TSS	
Longitude (⁰)	**Latitude (⁰)**	**In situ data 20 Avril 2016**	**Sentinel-2 12 January 2016**
112.8786	-7.5507	28	17.370579
112.8798	-7.5425	42.72	17.467878
112.8786	-7.5577	48	17.103432
112.8801	-7.5337	72	18.052235
112.8693	-7.5153	74	18.247227
112.8769	-7.5194	80	19.982183
112.8945	-7.569	74	18.176249
112.8947	-7.5804	68	17.658016
112.8825	-7.5308	72	18.833309

In order to assess the performance of algorithm applied in Sentinel-2, nine pixels points were extracted from TSS image result. Those nine points are located in the study areas as can be seen in Figure 7. In situ data was also extracted in the same coordinates of those nine points. Comparison between TSS from Sentinel-2 calculation and in situ data can be carried out in order to know their similarity.

Table 2 showed comparison of TSS values from Sentinel-2 and in situ data. From those comparison, correlation values can be calculated. Correlation about 0.72 was obtained which indicated good result of TSS estimation from Sentinel-2 image. The correlation value generated in this study meets the specified requirements, i.e. correlation ≥ 0.7.

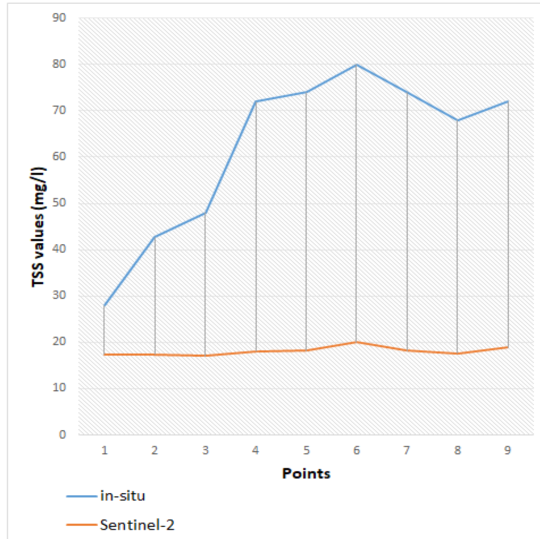
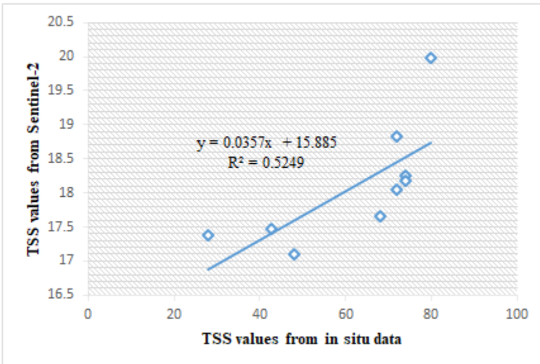


Figure 8. Graph comparison of TSS values between in situ data and calculated Sentinel-2 image.

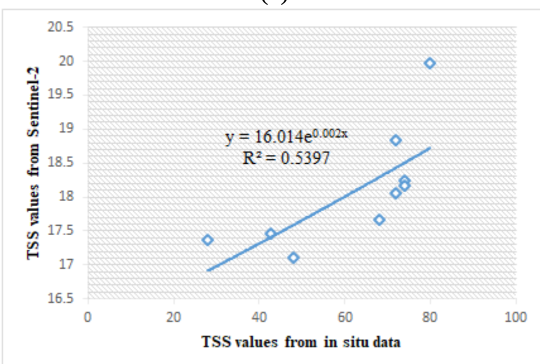
TSS values from in situ data relative different from TSS values from Sentinel-2 image (see Figure 8). In situ data tend to give higher TSS values than calculated Sentinel-2 image. However, the values have good correlation between each other and almost same trend. The reasons of different values can be because of some points explained below.

1. Different time between image acquisition and in situ data retrieval. A fairly prominent time interval may lead to changes or dynamics of aquatic conditions resulting modification of TSS values distribution.
2. It can be also because of we used BoA values, not remote sensing reflectance values.
3. The last reason, may be because of the algorithm actually addressed for Landsat-8.

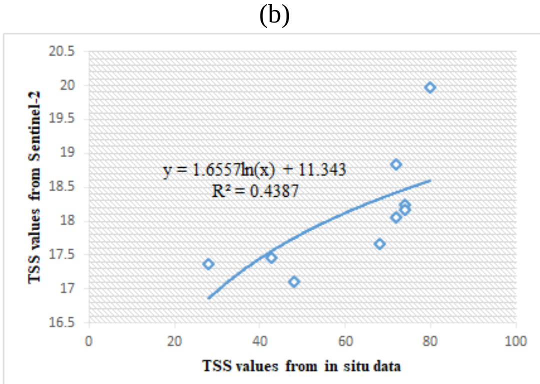
Cross-regression analyses between TSS values from Sentinel-2 and in situ data was done using three different curve fitting model. Figure 9 showed those three curve fitting models, i.e. linear, exponential, and logarithmic. From the figure, it can be seen that exponential give higher R^2 value. Linear model was resulted R^2 about 0.52, exponential model gave R^2 about 0.54, while logarithmic model gave lowest R^2 with value 0.44. This analysis reinforced the statement about suitability of exponential curve fitting model for estimating water constituents, such as TSS (Ha and Koike, 2011; Ha *et al.*, 2017).



(a)



(b)



(c)

Figure 9. Cross-relationships of TSS values between in situ data and Sentinel-2 imagery in three curve fitting models: (a) linear; (b) exponential; (c) logarithmic.

4. CONCLUSIONS

The objective of this study is to assess the suitability of Sentinel-2 data to estimate TSS concentration in the estuary of Porong River and Java Sea. To this end, we applied an algorithm from Laili (2015) which involving band 2 and band 4 of Sentinel-2 image. Using Sentinel-2 which has higher spatial resolution from Landsat-8, will optimize TSS monitoring. With spatial resolution for band 2 and band 4 at 10 meters and high revisit time, Sentinel-2 can provide better ability for TSS estimation.

Applied algorithm which actually is designed for Landsat-8 need some adaptation. In here, to adapt with Sentinel-2, BoA reflectance was used instead of remote sensing reflectance. The result is good enough to detect TSS using that algorithm. However, in order to obtain better results in the next research, it may be better to change BoA reflectance to remote sensing reflectance before apply the algorithm. Moreover, the parameters values must be changed in order to adapt more with Sentinel-2 pixel values distribution.

After all, the use of Sentinel-2 image for estimation of TSS is very applicable for future research. Large coverage areas, many variations of bands, high spatial and temporal resolution make Sentinel-2 application very promising.

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