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ESTIMATION OF TOTAL SUSPENDED SOLIDS IN THE UJUNG PANGKAH ESTUARY USING MULTI TEMPORAL SENTINEL-2 SATELLITE IMAGERY

Ika Kurnia Istriyani[1], Zainul Hidayah[1*], Dwi Budi Wiyanto[2]
[1]Marine Science and Fisheries Department, Faculty of Agriculture,
Trunojoyo University of Madura, Bangkalan Madura, East Java, 69162, Indonesia
[2]Marine Science Department, Faculty of Marine and Fisheries, Udayana University,
Bukit Jimbaran Campus Bali, 80361, Indonesia
*Correspondence : zainulhidayah@trunojoyo.ac.id
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ABSTRACT

The presence of dissolved materials in seawater, particularly Total Suspended Solids (TSS), significantly affects its optical properties. This phenomenon can be quantitatively observed through remote sensing techniques, which require various algorithms to convert pixel reflectance values into TSS concentrations. This study has two primary objectives: (1) to estimate and map TSS concentrations using multitemporal Sentinel-2 satellite imagery and (2) to compare multiple TSS estimation algorithms by analyzing satellite-derived data against in situ measurements. Sentinel-2 images from 2020 to 2022 were utilized, and TSS concentrations were derived using the Liu, Budiman, and Prasetyo algorithms. The satellite-derived TSS values were validated against field measurements from 25 sampling points. Accuracy was assessed using Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE). In situ measurements indicated that TSS concentrations in the study area ranged from 24 to 127 mg/L. The Liu and Budiman algorithms exhibited the highest standard deviation in TSS estimates, while the Prasetyo algorithm demonstrated lower deviations, yielding more reliable results. Statistical validation confirmed that the Prasetyo algorithm provided the most accurate estimation of in situ TSS concentrations (RMSE = 10.75, MAPE = 3.97%, R^2 = 0.85). These findings highlight the effectiveness of remote sensing for TSS monitoring and underscore the importance of selecting appropriate algorithms for accurate water quality assessment.
Keywords: algorithms, remote sensing, satellite image, Sentinel-2, total suspended solids

Estimasi Total Padatan Tersuspensi di Muara Ujung Pangkah menggunakan Citra Satelit Sentinel-2 Multitemporal

ABSTRAK

Keberadaan material terlarut dalam air, khususnya Total Suspended Solids (TSS), berpengaruh signifikan terhadap sifat optik air laut. Fenomena ini dapat diamati secara kuantitatif melalui teknik penginderaan jauh, yang memerlukan berbagai algoritma untuk mengonversi nilai reflektansi piksel menjadi konsentrasi TSS. Penelitian ini memiliki dua tujuan utama: (1) memperkirakan dan memetakan konsentrasi TSS menggunakan citra satelit multitemporal Sentinel-2 serta (2) membandingkan beberapa algoritma estimasi TSS dengan menganalisis data citra terhadap pengukuran in situ. Citra Sentinel-2 dari tahun 2020 hingga 2022 digunakan dalam penelitian ini, dan konsentrasi TSS dihitung menggunakan tiga algoritma: Liu, Budiman, dan Prasetyo. Hasil estimasi TSS dari citra satelit divalidasi dengan data lapangan dari 25 titik sampel. Akurasi estimasi diuji menggunakan parameter Root Mean Squared Error (RMSE) dan Mean Absolute Percentage Error (MAPE). Hasil pengukuran in situ menunjukkan bahwa konsentrasi TSS di wilayah penelitian berkisar antara 24 hingga 127 mg/L. Algoritma Liu dan Budiman menghasilkan estimasi TSS dengan standar deviasi tertinggi, sedangkan algoritma Prasetyo menunjukkan deviasi yang lebih rendah, menghasilkan estimasi yang lebih akurat. Validasi statistik mengonfirmasi bahwa algoritma Prasetyo memiliki keakuratan tertinggi dalam memperkirakan TSS in situ (RMSE = 10,75, MAPE = 3,97%, R^2 = 0,85). Hasil penelitian ini menegaskan efektivitas penginderaan jauh dalam pemantauan TSS serta pentingnya pemilihan algoritma yang tepat untuk penilaian kualitas air yang akurat.
***Kata kunci**: algoritma, citra satelit, penginderaan jauh, Sentinel-2, total suspended solids*

INTRODUCTION

Suspended sediment in water plays a significant role for measuring water quality. The suspended sediment serves as a medium for the transport of many binding contaminants, including nutrients, trace metals, semi-volatile organic compounds, and numerous pesticides (Zhang *et al.*, 2017). Total Suspended Solids (TSS) refers to the amount of material that enters the body of water, such as organic/inorganic materials or microorganisms (Bilotta and Brazier, 2008). Soil erosion, originating on land and subsequently carried by river flows into the sea, introduces suspended material into coastal waters. Anthropogenic activities in the form of deforestation, agriculture, and urbanization have had a significant impact on water quality, sediment transport, and erosion, which are all complex natural processes (Issaka and Ashraf, 2017; Milenia *et al*., 2021). In particular, suspended sediment plays an important role in controlling water quality, which can result in a significant reduction in stream capacity for handling flood waves (Nguyen *et al.*, 2020).

Turbidity is closely related to the concentration of suspended substances in the water column. High turbidity levels will affect the high levels of TSS in the water column, preventing sunlight from entering and reducing the photosynthesis rate (Bowers and Binding, 2006; Boss *et al.*, 2009; Kobayashi *et al.,* 2010). Furthermore, TSS affects dissolved oxygen, marine biogeochemical cycles, brightness levels, primary production processes in the ocean, and other parameters (Aniyikaiye *et al.*, 2019). Furthermore, the assessment of water quality has widely relied on TSS analysis. The higher the TSS value in the water, the higher the level of pollution due to the presence of insoluble materials that cannot settle directly.

The presence of dissolved materials in water causes visual changes in color and also affects sea water's optical properties. Remote sensing techniques can observe this measurable phenomenon (Umar *et al.,* 2018; Ross *et al.,* 2019). Over the last two decades, the assessment of suspended sediment has widely relied on optical remote sensing images. Estuaries, as opposed to large bodies of water such as lakes and reservoirs, are more immediately sensitive to and directly influenced by river bank characteristics, human activities, and other external forces. As a result, the effective use of remote sensing technology for monitoring suspended sediment loads in estuaries could be an exceptionally helpful instrument for coastal water quality monitoring.

Landsat satellite images are one of the most commonly used instruments for observing TSS due to their long operational period. The availability of multi-temporal satellite data has proven to be extremely beneficial in monitoring the TSS dynamics in coastal waters. Many locations, particularly in Indonesia, such as the Porong estuary in East Java, the Kampar estuary in Riau, the Berau estuary in East Kalimantan, Jakarta Bay, and Semarang City in Central Java, have conducted temporal observation of TSS using Landsat images (Wisha *et al.,* 2017; Zulfikar and Kusratmoko, 2017; Mubarok, 2019; Timurani, 2021). Most of the studies have provided low to moderate agreement of accuracy between field and remote sensing observations (R^2 ranges from 0.3 to 0.6). Other studies that used MODIS multi-temporal images produced relatively similar results (Wibisana and Wardhani, 2022). Based on previous research, this study intends to estimate TSS concentration in coastal waters using higher spatial resolution Sentinel-2 satellite imagery data.

Estimating TSS concentration using remote sensing methods requires the use of various algorithms that can convert pixel reflectance values into TSS concentration. The Liu algorithm (2017), Budhiman algorithm (2004), and Prasetyo algorithm (2019) are the most common algorithms applied to estimate TSS in coastal waters.

Due to their acceptable accuracy (R^2>0.6), the three algorithms were applied in this study. The study's location is the Ujung Pangkah estuary. Administratively located in Gresik regency of East Java Province, the Ujung Pangkah estuary marks the end of the Bengawan Solo river, one of Indonesia's longest rivers. The community makes extensive use of the coastal area at Ujung Pangkah as a traditional port, boat entry and exit route, and fish ponds. There is also a mangrove conservation area in this area. The study's goals are to first estimate and map TSS concentration using Sentinel-2 data from multiple time periods and then to compare different image-based algorithms for TSS concentration with measurements taken in real time. We anticipate that the findings will offer insights into the distribution of TSS in the coastal water of the study area, and enhance our understanding of water quality analysis through satellite images.

RESEARCH METHODS

Study Location

This study was conducted in the Ujung Pangkah estuary, Gresik Regency, East Java Province. The Ujung Pangkah coastal area borders directly on the waters of the Java Sea in the north. Ships from the eastern part of Indonesia head south through the waters of the western Surabaya shipping lane, which includes the western side of Ujung Pangkah. Surface water sampling for TSS analysis was carried out at 25 observation points on a weekly basis in August 2023 (Figure 1). TSS values were measured using the gravimetric method according to SNI 06-6989.3-2004 at the Oceanographic Laboratory of Trunojoyo University Madura in September-October 2023.

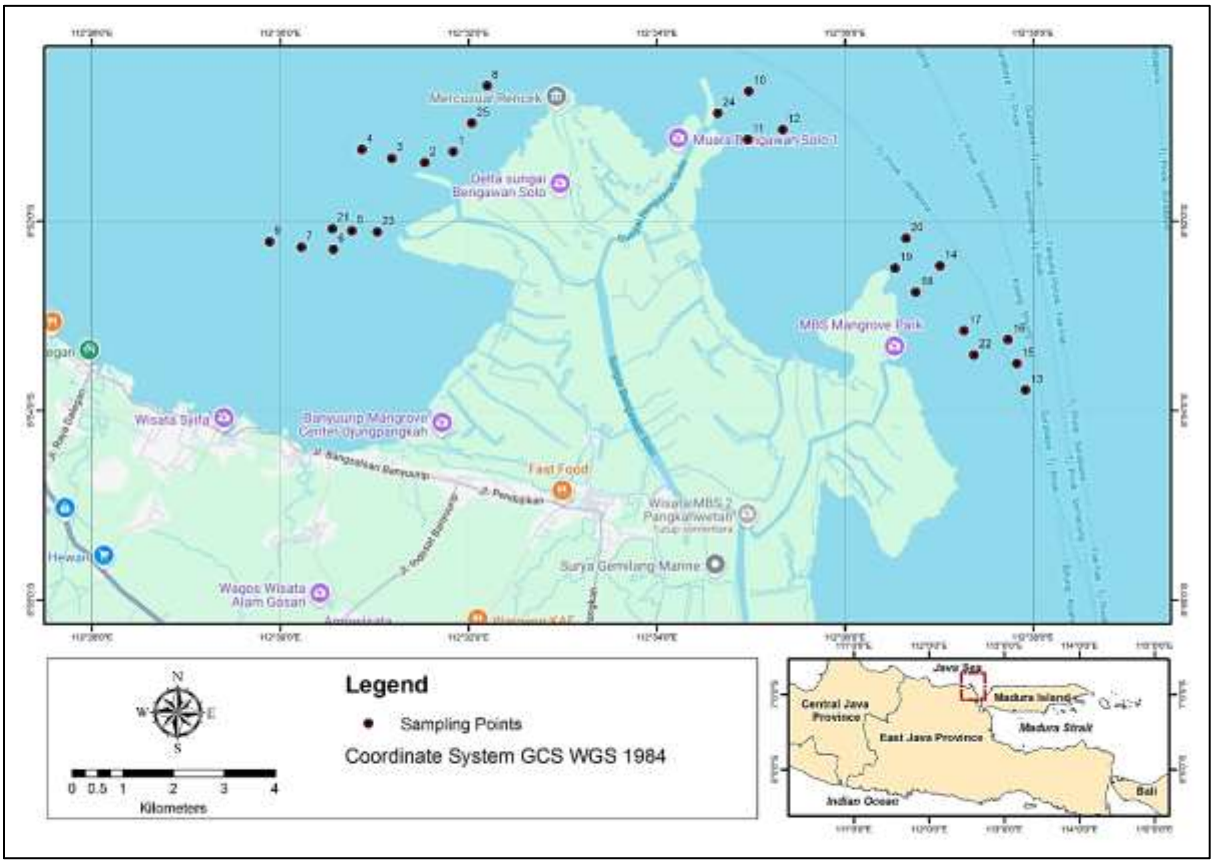

Figure 1. Map of Ujung Pangkah estuary and location of 25 water sampling points

Remote Sensing Data

Multi-temporal Sentinel-2 images from 2020-2022 were used for this study. We chose the image acquisition period to closely align with the field data collection time, specifically between July and August 2023. The acquisition date of the 2020 image was July 17th, whereas the other images were acquired in August 10th, 2021, and August 19th, 2022, respectively. The Sentinel-2 image consists of 13 bands with a spatial resolution of 10, 20, and 60 meters. Spectral characteristics for Sentinel-2 imagery are presented in Table 1. For this research, Sentinel-2 imagery was downloaded from the following websit address: https://scihub.copernicus.eu

SNAP software was used to process Sentinel-2A image data. The downloaded image is then corrected using the Bottom of Atmosphere (BoA) method, which is designed to remove atmospheric effects. Sen2Core toolbox which is included in the SNAP software, can be used to perform the BoA correction process. The image is then resampled, which is a geometric correction process that adjusts the resolution in each band with a resolution of 10 m and sharpens the image. The resampled image is then subsetted to fit the image in the research area. Moreover, image Masking is then used to separate land and water areas. The NDWI (Normalized Difference Water Index) algorithm is used for masking. The algorithm's output divides the image into pixel value classes. If NDWI pixel>0 then the area is difined as land, in contrast if NDWI pixel<0 the area is defined as water. Moreover, three TSS algorithms namely Liu (2017), Budhiman (2004) and Prasetyo (2019) were applied to selected area and the results are compared to laboratory measurement's of in situ TSS (Figure 2).

Table 1. Sentinel-2 image spectral characteristics

Sentinel-2 Bands	Central Wavelenght (μm)	Spatial Resolution (m)
Band 1 – Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation Red Edge	0.705	20
Band 6 – Vegetation Red Edge	0.740	20
Band 7 – Vegetation Red Edge	0.783	20
Band 8 – NIR	0.842	10
Band 8A – Vegetation Red Edge	0.865	20
Band 9 – Water Vapour	0.945	60
Band 10 – SWIR Cirrius	1.342	60
Band 11 – SWIR	1.610	20
Band 12 – SWIR	2.190	20

Source : https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/overview

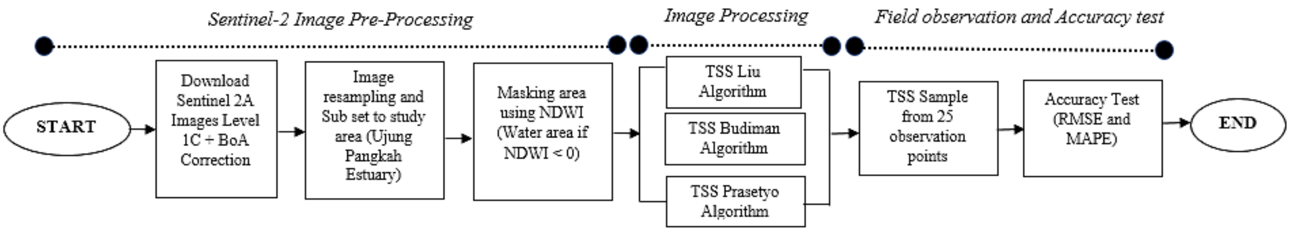

Figure 2. Flowchart of image processing and data analysis

Furthermore, TSS estimations were performed on Sentinel-2 images acquired in 2020-2022 using three algorithms namely Liu algorithm (2017), Budhiman algorithm (2004) and Prasetyo algorithm (2019). The three algorithms were used in this study because they are commonly used to determine TSS concentrations in tropical waters, particularly in Indonesia, where the characteristics are similar to the study areas.

The Budhiman algorithm (2004) and the Prasetyo algorithm (2019) use the red band of Sentinel-2 as the primary data because it has a wavelength of 665 nm, which is capable of detecting suspended material content in waters. Meanwhile, Liu algorithm (2017) makes use of Sentinel-2 infrared band at 783 nm, which can distinguish between clean and polluted waters. The NDWI calculation and three algorithms used to extract TSS values from Sentinel-2 satellite imagery are as follows:

$$NDWI = \frac{(B3-B11)}{(B3+B11)}, Water\ if\ NDWI < 0 \text{....(1)}$$

$$TSS\ Liu\ (mg/l) = 2950\ x\ B7^{1.357} \text{..............(2)}$$

$$TSS\ Budhiman\ (mg/l) = 8{,}1429\ x\ exp^{(27.704\ x\ 0.94\ x\ B4)} \text{...(3)}$$

$$TSS\ Prasetyo\ (mg/l) = 3{,}7321\ x\ exp^{(12.543\ x\ (B3+B4)} \text{...(4)}$$

Notes: B3, B4, B7, B11 represents number of bands of Sentinel-2 imagery data.

Laboratory TSS Analysis

Laboratory TSS analysis was conducted in accordance to SNI 06-6989.3-2004 for the TSS test using the gravimetric method. The gravimetric method ensures the deposition of solid substances that are not dissolved in water. TSS analysis is performed by filtering homogenized seawater samples, then transferring 10 mL to filter paper. The filter paper containing residue or solids is then heated up for 1 hour at 103°C-105°C. After 1 hour in the oven, the sample was cooled in a desiccator for 15 minutes before weighing to determine the weight of the filter paper and residue. Repeat these steps until obtaining a residue weight between 2.5 mg and 200 mg. This study used a 250 ml water sample volume from each sampling plots to determine a constant residual weight. After getting the final weight, the calculation of TSS gravimetri was performed using equation 1.

$$TSS\ (mg\ /\ l) = \frac{(A-B)\times 1000}{Volume\ (L)} \text{...........................(5)}$$

Notes: A = Filter paper and residu (g); B = Filter paper (g); V = Water sample volume (ml).

Accuracy Test

After determining the TSS concentration, an accuracy test was carried out by comparing TSS concentration from field data to image processing results from Sentinel-2A images. The difference between measurements was represented by the RMSE and MAPE values. The equation of accuracy tests as follows.

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}(Y-Y\prime)^2}{n}} \text{................................... (6)}$$

$$MAPE = \frac{1}{n}\Sigma\left|\frac{Y-Y'}{Y}\right| \times 100\% \text{......................... (7)}$$

In equation 2 and 3 above, Y represents TSS values from laboratory analysis, meanwhile Y' represents TSS values from image processing. Additionally n is number of data which represented by the number of sampling points of this study. In this study, the use of two methods for measuring accuracy aims to emphasize the results and reduce bias. Root Mean Squared Error and MAPE have certain characteristics in determining the level of data accuracy. Root Mean Squared Error is the most commonly used accuracy evaluation method. This method produces absolute values and takes into account the weight of errors when calculating data accuracy. Meanwhile, MAPE provides relative values, making it useful in situations where predictions are dependent on the percentage of errors.

RESULTS AND DISCUSSION

Field Measurements of TSS

Laboratory TSS analysis was conducted after collecting field data in the form of water samples from 25 locations. The results of the in situ data analysis revealed that the average concentration of TSS values in Muara Bengawan Solo ranged from 24 to 127 mg/l. According to the Minister of Environment's Decree No. 115 of 2003 on Guidelines for Determining Water Quality Status, this value indicates that the TSS concentration in estuarine waters exceeds the water quality standard threshold of 20–80 mg/L. Figure 3 compares TSS values between water sampling locations, revealing different characteristics in TSS concentrations at sample points. TSS concentrations in the vicinity of river mouths and mangrove areas are significantly higher than at sample points in open waters ($p < 0.05$). Table 2 presents the more detailed statistical parameters of the TSS laboratory results analysis.

The high concentration of TSS will affect the water's brightness, influencing various biological activities in the water column. The high concentration of TSS at the mouth of

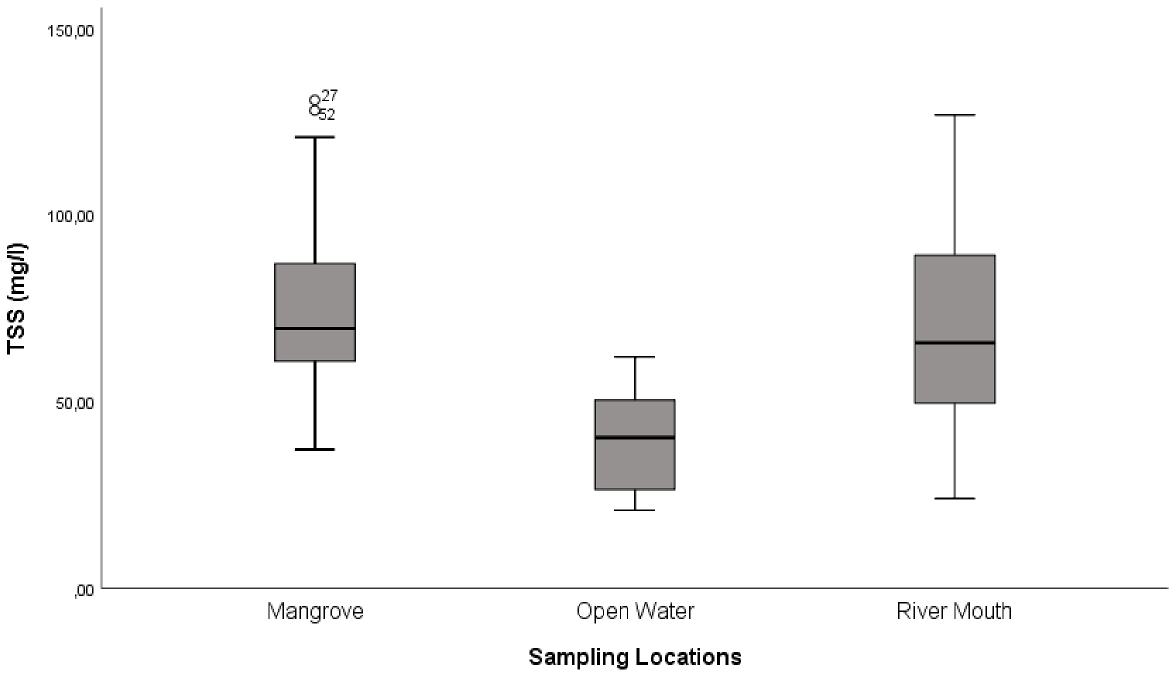

Figure 3. Results of TSS laboratory analysis based on sampling locations (significant difference, $p < 0.05$)

Table 2. Statistical parameter of laboratory TSS analysis (mg/l)

Locations	N	Mean	Median	SD	Max	Min	SE
Mangrove	24	75.38	69.00	24.37	130.80	37.00	4.97
Open Water	21	40.37	40.40	14.05	62.00	20.80	3.06
River Mouth	30	68.74	65.80	29.96	126.80	24.00	5.47

the Bengawan Solo River indicates that the river flow carried a large amount of sediment, which ended up at the river mouth. Furthermore, through a complex hydrological process involving currents and water movement, the sediment dissolved in the water will gradually settle and lead to sedimentation. This process produces mud deposits, which become a medium for mangrove growth (Hidayah *et al.,* 2023). As the current moves away from the river mouth, the concentration of TSS decreases due to the precipitation of the majority of suspended solids (Wiryamanta *et al.*, 2021). In addition, current speed is another factor influencing TSS concentration changes. Fast-flowing water transports larger particles and sediments. Heavy rains can transport sand, mud, clay, and other organic particles from land to sea. However, when the speed of the current decreases, sediment particles can accumulate. Tides also influence the distribution of sediment. High tides distribute water from the sea to the river, causing suspended sediment to flow from the sea to the river and *vice versa* (Mubarok *et al.*, 2019).

Image Analysis

After going through several stages of image processing, namely atmospheric correction, geometric correction, image subset and separating land and water using the NDWI index, then the TSS algorithm is applied. Figure 4 depicts the spatial distribution of TSS over the observed time periods. The results of analysis particularly for the 2020 image acquisition date July 17th revealed that the TSS concentration ranges from 17 mg/L to 181 mg/L, according to the Liu algorithm. TSS concentrations are highest at the river mouth, exceeding 130 mg/L, and towards the open sea the concentration values decrease to less than 40 mg/L. The Budhiman algorithm produces a wider range of TSS concentrations, ranging from 18 mg/L to 283 mg/L. The TSS concentration near the river mouth is greater than 45 mg/L. Whereas the Prasetyo algorithm yielded TSS concentration results ranging from 15 to 206 mg/L (Figure 4A).

The next results are based on the image taken on August 10th, 2021 (Figure 4B). The Liu algorithm processing produced TSS concentrations ranging from 14 mg/L to 111 mg/L. TSS concentrations are highest around estuaries and in waters near mangroves, ranging from 32 mg/L to over 100 mg/L. The Budhiman algorithm obtained TSS concentrations that varied between 23 mg/L to 137 mg/L, whereas the Prasetyo algorithm obtained values ranging from 24 mg/L to 101 mg/L. The TSS concentration in open waters for both algorithms extends from 24 to 40 mg/L.

Finally, according to the image analysis acquisition date August 17th 2022 (Figure 4C) following Liu's algorithm, the TSS concentration near Ujung Pangkah's river mouth ranges from 30 mg/L to 100 mg/L, while in open waters it is less than 30 mg/L. Meanwhile, the Budiman and Prasetyo algorithms showed almost identical TSS concentration ranges of 40 mg/L to 100 mg/L.

As in the results of direct sampling, multi-temporal image analysis shows high TSS content at the research location and exceeds the quality standard of 20–80 mg/l, as shown by direct sampling results. Of course, the main cause is the high volume of sediment that the Bengawan Solo-river flow carries and releases in the Ujung Pangkah estuary area. According to data from the Bengawan Solo Water Resources Management Centre (BPSDA), the river discharge in July-August ranged from 160.20 m^3/s to 201.53 m^3/s, with a sediment load of 23.92 to 58.31 kg/s. Poor water quality and a potential increase in temperature in the upper stratum of the water column can result from high sediment loads (Dethier *et al.*, 2022). Suspended particulates can contribute to adverse environmental conditions in the water column by transporting heavy metals, pollutants, and nutrients. The productivity of the ecosystem is diminished and the ecosystem's functioning is altered as a result of the excessive near-surface accumulation of this optically significant water constituent, which effects light propagation into deeper layers and the benthos (Varol, 2020). In contrast, sediment loading is essential for the preservation of sediment-maintained geomorphic features, including river deltas, marsh and mangrove wetland platforms, and sediment accretion rates (Wisha *et al.,* 2017). These coastal features are damaged when sediment dynamics are compromised by upstream trapping of suspended sediments by reservoirs, river channelization and disturbance of delta distributary flows, and sea level rise.

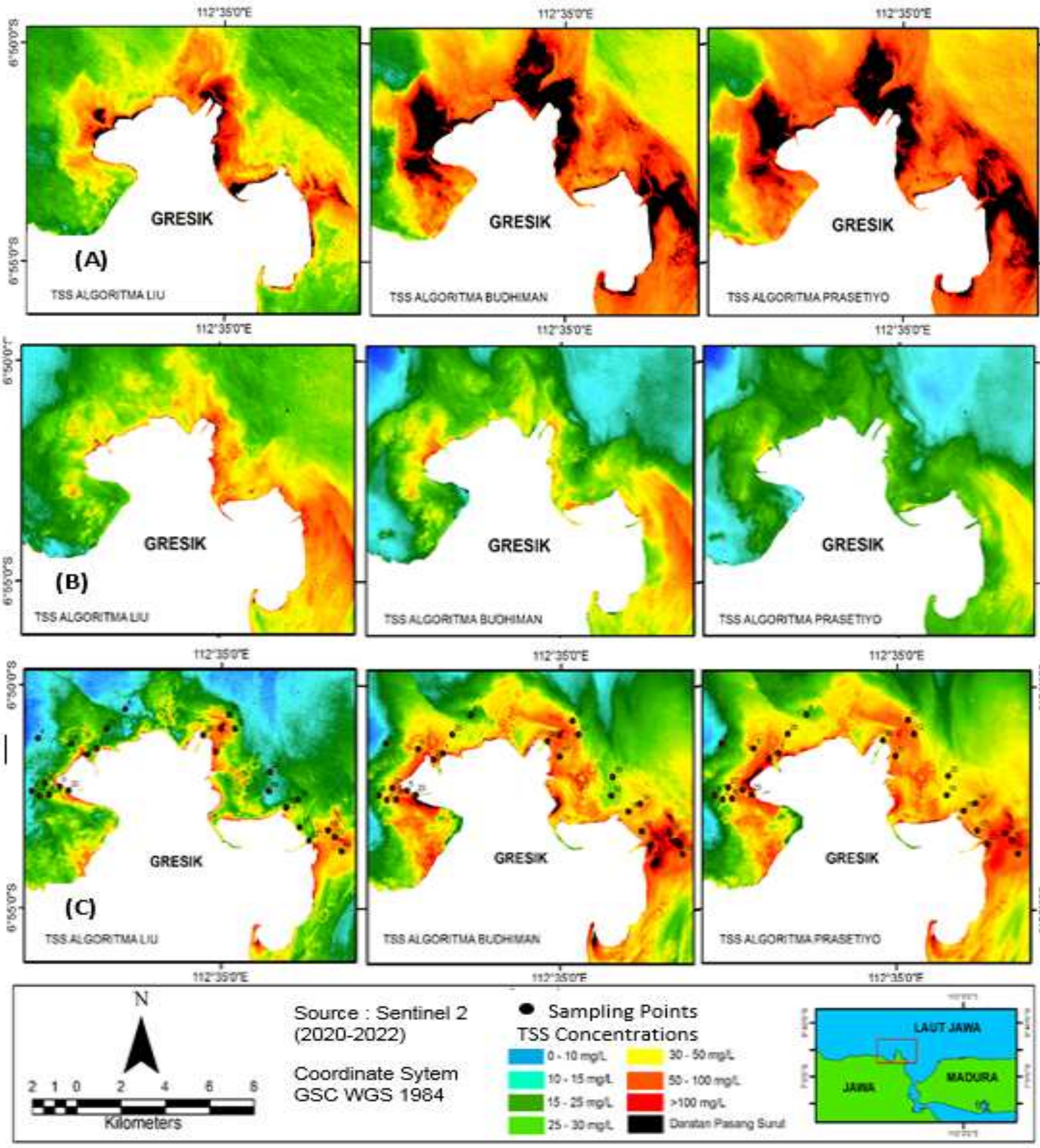

Figure 4. Spatial Distribution of TSS Based on Liu, Budiman and Prasetyo Algorithms (A) July 17th 2020; (B) August 10th 2021; (C) August 19th 2022

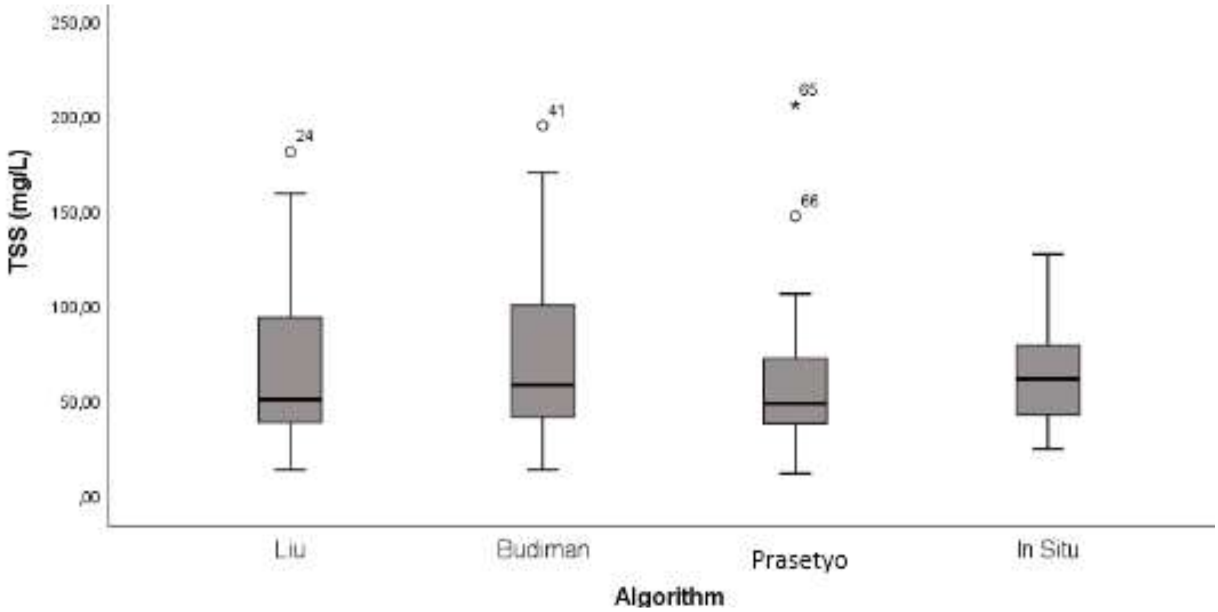

Figure 5. Results of TSS analysis based on Sentinel-2 image processing and in-situ data (no siginificant difference, p >0.05)

Table 3. Statistical parameter of TSS analysis (mg/l) based on image processing (2020-2022)

Algorithm	N	Mean	Median	SD	Max	Min	SE
Liu	75	64.50	50.00	39.22	181.00	13.00	4.52
Budiman	75	72.58	58.00	47.65	283.00	13.00	5.50
Prasetyo	75	56.58	48.00	31.90	206.00	11.00	3.68
In-Situ Data	75	63.00	61.00	28.15	127.00	24.00	3.25

A comparison of the results from the three TSS estimation algorithms and field data reveals no significant differences (p >0.05). Budiman's algorithm outperforms both in situ data and other algorithms in terms of TSS average and median. The Liu and Budiman algorithms produces the TSS estimate with the highest standard deviation (Figure 5). Meanwhile, Prasetyo algorithm and field data exhibit smaller deviations. In addition, Liu and Budiman's algorithm has a higher standard error than the other two measurement results (Table 3).

Accuracy of Image Processing

To determine the accuracy of measuring TSS values using satellite imagery, the results of Sentinel-2 image processing were compared to laboratory analysis from field sampling. The image for comparison is a Sentinel-2 image captured on August 19th 2023, alongside field data gathered in July 30th 2023. We closely aligned the coordinates of the chosen pixel values from the satellite image with 25 data collection locations. The results are presented in Table 4.

Comparing the measured TSS concentrations from field data collection and image processing (Table 4) shows that, on average, the estimated TSS concentrations from all image processing algorithms are pretty good when compared to the field measurements (RMSE <30 and MAPE <10%). The RMSE value for the Prasetyo algorithm is 10.75, while the RMSE values for the other algorithms are 15.54 and 11.38, respectively. Meanwhile, the results also explain that the Prasetyo algorithm's MAPE percentage is the lowest compared to the Liu

Table 4. Comparison of TSS from Sentinel-2 image processing and field data

Sampling Points	Coordinate		TSS In Situ (mg/L)	Image Processing TSS (mg/L) Algoritms		
	Latitude	Longitude		Liu	Budhiman	Prasetyo
1	112°31'51"	6°51'21"	79	54	98	67
2	112°31'34"	6°51'27"	127	111	134	82
3	112°31'10"	6°51'11"	42	16	41	35
4	112°30'19"	6°51'03"	24	17	14	12
5	112°30'52"	6°52'10"	88	20	58	46
6	112°30'31"	6°52'20"	51	16	40	33
7	112°29'56"	6°52'21"	25	18	16	13
8	112°32'33"	6°50'20"	32	19	23	23
9	112°29'36"	6°52'14"	24	17	13	11
10	112°35'17"	6°50'27"	29	16	38	37
11	112°34'59"	6°51'20"	63	31	49	40
12	112°35'26"	6°50'48"	57	14	40	39
13	112°38'10"	6°53'44"	65	30	60	50
14	112°37'06"	6°52'30"	69	23	60	54
15	112°38'02"	6°53'24"	102	72	113	81
16	112°37'50"	6°53'15"	123	91	141	106
17	112°37'07"	6°53'10"	64	19	56	48
18	112°37'46"	6°52'41"	73	32	46	40
19	112°36'21"	6°52'16"	58	10	31	31
20	112°36'22"	6°51'49"	43	13	35	34
21	112°30'27"	6°52'07"	55	15	35	30
22	112°37'15"	6°53'31"	92	126	135	84
23	112°31'12"	6°52'13"	84	82	110	65
24	112°34'37"	6°50'58"	61	42	54	40
25	112°32'65"	6°50'48"	43	17	43	36
Mean ±Stdev			63±28.5	35±15.3	59±18.7	43±13.8
RMSE				15.54	11.38	10.75
MAPE (%)				9.90	5.41	3.97

and Budhiman algorithms. Another finding from a previous study confirms that using the PRASETYO algorithm to estimate TSS on a Sentinel-2 image produces reasonably accurate results (Prasetiyo *et al.*, 2019). This study assessed accuracy using MAPE and RMSE values. These two parameters are commonly used to assess calculation bias between two or more different approaches. In addition, these two statistical parameters be used as as a guide to choose the most suitable algorithm. The RMSE and MAPE method statistical tests have the following interpretation: The lower the value, the closer it is to zero, the better the resulting algorithm model.

This study includes additional analysis to validate the results. Regression models are used to identify patterns or relationships between in-situ TSS measurements and image processing results. In this analysis, image processing results are used as the independent variable (X), and field data collection results are used as the dependent variable (Y). Regression models and graphs are presented in Figure 6. The regression analysis results show that the three developed models are capable of explaining the connection between TSS concentrations obtained through image processing and field data collection results. The coefficient of determination (R^2) value is greater than 0.6, indicating that the regression models

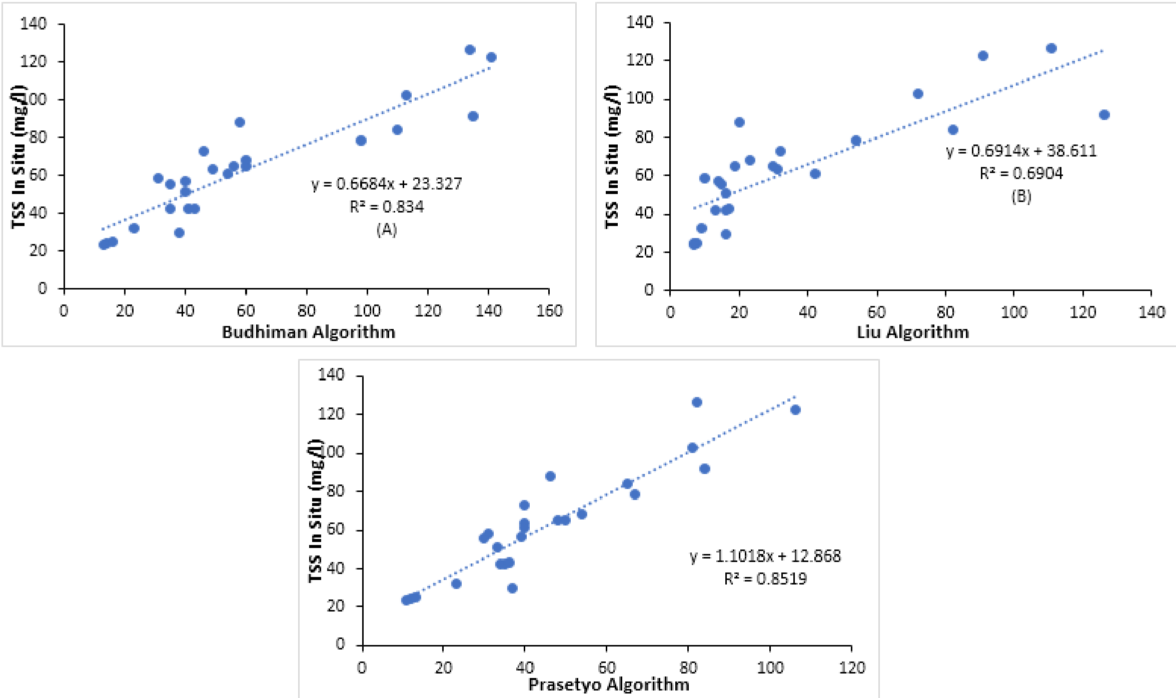

Figure 6. Regression models of image processing TSS (X-axis) and in-situ TSS (Y-axis)

obtained are valid. However, further comparison reveals that the model generated by the Prasetyo algorithm has R^2 =0.85, which is significantly higher than the other two models' R^2 values of 0.73 and 0.69, respectively. Therefore, it can be argued that in this study, PRASETYO algorithm using Sentinel-2 image is more accurate to estimate TSS. This result gives more confirmation regarding the validity of Prasetyo algorithm in TSS estimation.

However, the result of this study is apparently location specific and need more tests to be applied in other locations. A recent study using Sentinel-2 imagery data in East Flood Canal Estuary of Semarang (Al Faridzie *et al.*, 2023) revealed that Prasetyo algorithm is fairly accurate to estimate in-situ TSS (R^2 =0.61), nonetheless this model produced RMSE =35.52 and MAPE =61.97% which is much higher compare to the results of this current study in Ujung Pangkah estuary. The considerably high bias was thought to be driven by dynamic hidrological processes in the estuary, along with a time difference between field data collection and image acquisition.

The Sentinel 2A remote sensing imagery, as well as the derivation of horizontal variations in TSS, provide a solid foundation for comparisons with field data collection in the estuary regions. The combination of remote sensing and modeling that has been used in this study can provide a powerful tool for improving TSS predictions and increasing confidence in modeling various water quality and related coastal management scenarios (Nguyen *et al.*, 2020). Future works should focus on using additional sensors in Sentinel-2A and developing algorithms to improve spatial estimation of TSS concentration in the estuary. Sentinel-2A has been shown to provide high-quality estimates of suspended sediments and should be used to assess other optical properties of sea water.

CONCLUSION

This study has demonstrated the ability of using Sentinel-2 satellite imagery data to estimate TSS concentration in Ujung

Pangkah estuary of East Java. In-situ data analysis revealed that the average TSS concentration ranged between 24 and 127 mg/l. TSS concentrations are significantly higher near river mouths and mangrove areas than at sample points in open waters. The Liu and Budiman algorithm produces the TSS estimate with the highest standard deviation. In contrast to the Prasetyo algorithm data which show smaller deviations. In this study, Prasetyo is more valid to estimate in-situ TSS compare to Budiman and Liu algorithm with RMSE =10.75, MAPE =3.97% and R^2 of regression model =0.85.

REFERENCES

Al Faridzie, M., Maslukah, L., Ismunarti, D. H., & Wirasatriya, A. (2023). Uji akurasi beberapa algoritma material padatan tersuspensi menggunakan citra Sentinel-2A di Muara Banjir Kanal Timur Semarang. *Jurnal Kelautan Tropis, 26*(3), 503–513. https://doi.org/10.14710/jkt.v26i3.17496

Aniyikaiye, T. E., Oluseyi, T., Odiyo, J. O., & Edokpayi, J. N. (2019). Physico-chemical analysis of wastewater discharge from selected paint industries in Lagos, Nigeria. *International Journal of Environmental Research and Public Health, 16*(7), 1235. https://doi.org/10.3390/ijerph16071235

Bilotta, G. S., & Brazier, R. E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. *Water Research, 42*(12), 2849–2861. https://doi.org/10.1016/j.watres.2008.03.018

Boss, E., Taylor, L., Gilbert, S., Gundersen, K., Hawley, N., Janzen, C., & Tamburri, M. N. (2009). Comparison of inherent optical properties as a surrogate for particulate matter concentration in coastal waters. *Limnology and Oceanography: Methods, 7*(11), 803–810. http://dx.doi.org/10.25607/OBP-358

Bowers, D. G., & Binding, C. E. (2006). The optical properties of mineral suspended particles: A review and synthesis. *Estuarine, Coastal and Shelf Science, 67*(1–2), 219–230. https://doi.org/10.1016/j.ecss.2005.11.010

Budhiman, S. (2004). *Mapping TSM concentrations from multi sensor satellite images in turbid tropical coastal waters of Mahakam Delta Indonesia*. ITC Enschede.

Dethier, E. N., Renshaw, C. E., & Magilligan, F. J. (2022). Rapid changes to global river suspended sediment flux by humans. *Science, 376*(6600), 1447–1452. https://doi.org/10.1126/science.abn7980

Hidayah, Z., Maula, M., & Wardhani, M. K. (2023). Pemodelan arus dan muatan padatan tersuspensi di perairan estuari muara Bengawan Solo Ujung Pangkah Gresik. *Buletin Oseanografi Marina, 12*(1), 87–97. https://doi.org/10.14710/buloma.v12i1.42322

Issaka, S., & Ashraf, M. A. (2017). Impact of soil erosion and degradation on water quality: A review. *Geology, Ecology, and Landscapes, 1*(1), 1–11. https://doi.org/10.1080/24749508.2017.1301053

Kobayashi, H., Toratani, M., Matsumura, S., Siripong, A., Lirdwitayaprasit, T., & Jintasaeranee, P. (2010). Optical properties of inorganic suspended solids and their influence on coastal ocean color remote sensing. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* 997–1001.

Liu, H., Li, Q., Shi, T., Hu, S., Wu, G., & Zhou, Q. (2017). Application of Sentinel 2 MSI images to retrieve suspended particulate matter concentrations in Poyang Lake. *Remote Sensing, 9*(7), 761. https://doi.org/10.3390/rs9070761

Milenia, A. P., Wirasatriya, A., Maslukah, L., Yusuf, M., & Helmi, M. (2021). Distribusi material padatan tersuspensi di perairan Semarang dengan penginderaan jauh. *Indonesian Journal of Oceanography, 3*(3), 280–285. https://doi.org/10.14710/ijoce.v3i3.11704

Mubarok, E. S. (2019). The effect of organizational culture and work motivation on employee performance: The mediating role of job satisfaction. *European Journal of Business and Management*, 69–79. https://doi.org/10.7176/ejbm/11-35-09

Mubarok, I. D., Rifardi, R., & Tanjung, A. (2019). Studi temporal perubahan TSS (Total Suspended Solid) di perairan sekitar muara Kali Porong akibat pengaruh lumpur Lapindo berdasarkan interpretasi citra Landsat 8 OLI. *Jurnal Perikanan dan Kelautan, 24*(2), 119–129.

Nguyen, T. H. D., Phan, K. D., Nguyen, H. T. T., Tran, S. N., Tran, T. G., Tran, B. L., & Doan, T. N. (2020). Total suspended solid distribution in Hau River using Sentinel 2A satellite imagery. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 6*, 91–97. https://doi.org/10.5194/isprs-annals-VI-3-W1-2020-91-2020

Prasetiyo, B. A., Rochaddi, B., & Satriadi, A. (2019). Aplikasi citra Sentinel-2 untuk pemetaan sebaran material padatan tersuspensi di muara sungai Wulan Demak. *Journal of Marine Research, 8*(4), 379–386. https://doi.org/10.14710/jmr.v8i4.25193

Ross, M. R., Topp, S. N., Appling, A. P., Yang, X., Kuhn, C., Butman, D., & Pavelsky, T. M. (2019). AquaSat: A data set to enable remote sensing of water quality for inland waters. *Water Resources Research, 55*(11), 10012–10025. http://dx.doi.org/10.1029/2019WR024883

Timurani, E. C. (2021). Pemanfaatan citra satelit Landsat 8 dalam analisis kondisi perairan pesisir kota Semarang Jawa Tengah melalui penilaian konsentrasi Total Suspended Solid (TSS). *Skripsi Program Studi Geografi Universitas Muhammadiyah Surakarta*. http://eprints.ums.ac.id/id/eprint/90158

Umar, M., Rhoads, B. L., & Greenberg, J. A. (2018). Use of multispectral satellite remote sensing to assess mixing of suspended sediment downstream of large river confluences. *Journal of Hydrology, 556*, 325–338. https://doi.org/10.1016/j.jhydrol.2017.11.026

Varol, M. (2020). Use of water quality index and multivariate statistical methods for the evaluation of water quality of a stream affected by multiple stressors: A case study. *Environmental Pollution, 266*, 115417. https://doi.org/10.1016/j.envpol.2020.115417

Wibisana, H., & Wardhani, P. C. (2022). Analysis of the distribution of total suspended solids on the coastal Sampang coast due to the Blega river flow using satellite image data. *NSTP*, 1–9. https://doi.org/10.11594/nstp.2022.2701

Wiryamanta, D. R., Sumiadi, S., & Dermawan, V. (2021). Kajian distribusi konsentrasi sedimen suspensi menggunakan TSS meter pada sungai Brantas di Desa Pendem Kota Batu. *Jurnal Teknologi dan Rekayasa Sumber Daya Air, 1*(2), 379–392. https://doi.org/10.21776/ub.jtresda.2021.001.02.04

Wisha, U. J., Dhiauddin, R., & Kusumah, G. (2017). Remote estimation of Total Suspended Solid (TSS) transport affected by Tidal Bore "Bono" of Kampar Big River estuary using Landsat 8 OLI imagery. *Marine Research in Indonesia*, *42*(1), 37–45. https://doi.org/10.14203/mri.v42i1.116

Wisha, U. J., Ondara, K., & Kusumah, G. (2017). An overview of surface water quality influenced by suspended solid content in the Sayung Waters, Demak, Indonesia. *Jurnal Segara*, *13*(2). http://dx.doi.org/10.15578/segara.v13i2.6446

Zhang, C., Zhang, W., Huang, Y., & Gao, X. (2017). Analyzing the correlations of long-term seasonal water quality parameters, suspended solids and total dissolved solids in a shallow reservoir with meteorological factors. *Environmental Science and Pollution Research*, *24*, 6746–6756. https://link.springer.com/article/10.1007/s11356-017-8402-1

Zulfikar, A. A., & Kusratmoko, E. (2017). Pola sebaran Total Suspended Solid (TSS) di Teluk Jakarta sebelum dan sesudah reklamasi. *8th Industrial Research Workshop and National Seminar*, 496–502. https://corona.jatengprov.go.id/data