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Total suspended solid distribution mapping using sentinel-2A imagery in Ketapang Waters, South Lampung

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ABSTRACT

The distribution of total suspended solids (TSS) in coastal waters significantly affects water turbidity and light penetration, which affects aquatic ecosystems. The research aimed to compare the accuracy of algorithms using Sentinel-2A imagery to map the distribution of TSS in Ketapang Waters, South Lampung. Polynomial regression analysis and validation tests using R^2 and RMSE were performed to assess accuracy. The results showed that the Laili algorithm performed better, achieving an R^2 value of 0.9723 and a lower RMSE of 0.639, with TSS concentrations ranging from 17.26 to 22.90 mg/L. The derived third-order polynomial regression model $y = -0.0228x^3 + 1.3401x^2 - 25.16x + 170.08$ effectively predicted TSS concentrations. Spatial distribution analysis showed higher TSS levels near the coastline, likely due to sediment input from human activities and natural hydrodynamic processes, which gradually decreased towards the offshore area. These findings demonstrate the potential of the Laili algorithm for remote sensing-based water quality monitoring in dynamic coastal environments. Future research should include seasonal variations and explore the integration of multiple algorithms to improve the accuracy of TSS estimation and better understand temporal fluctuations in coastal sediment dynamics.

Keywords: coastal water, Ketapang Waters, remote sensing, sentinel-2, total suspended solid

INTRODUCTION

South Lampung Waters, encompassing the western and eastern coasts of Lampung Bay, had intensive coastal activities, including shipping routes, aquaculture, ports, industry, and household waste disposal. These activities contribute pollutants to the waters, leading to an increased Total Suspended Solids (TSS) concentrations (Winnarsih et al., 2016). TSS affects water turbidity and reduces light penetration, which disrupts photosynthesis for marine life, such as phytoplankton, and impacts the ecosystem, including fisheries and other aquatic biota (Silmina et al., 2020; Wang et al., 2017). Monitoring TSS concentrations, therefore, serves as a crucial indicator of water quality and pollution levels (Miranda et al., 2021).

Historically, TSS measurements have been conducted through in-situ sampling; however, technological advancements now allow for remote sensing via satellite imagery, which provides a practical, wide-area monitoring solution (Caballero et al., 2018; Nguyen et al., 2020). Sentinel-2 imagery had been used successfully to estimate TSS concentrations by applying algorithms that translate pixel values into TSS estimates, demonstrating feasibility in various regions (Ajiperwata et al., 2023; Liu et al., 2017). For example, studies in Tanjung Jati and Delta Wulan indicate that algorithms applied to Sentinel-2 can accurately represent TSS distribution, though results were often location-specific (Octaviana et al., 2020; Prayoga & Barus, 2021).

Despite these advancements, TSS monitoring in South Lampung had yet to be optimized using algorithms calibrated explicitly for the region's unique hydrodynamics and sediment profiles. Most existing algorithms, such as those by Laili (2015) and Jaelani (2016), have not been validated in Ketapang Waters, where local conditions may affect their accuracy. This study seeks to fill this gap by comparing the effectiveness of the Laili and Jaelani algorithms on Sentinel-2A imagery for TSS mapping in Ketapang Waters. Results will offer a foundation for further research into sedimentation and water quality assessments in South Lampung. The objective of this research was to compare the accuracy of the Laili (2015) and Jaelani (2016) algorithms using Sentinel-2A imagery to map the distribution of TSS in Ketapang Waters, South Lampung.

MATERIALS AND METHODS

Sampling Station

The research location points consist of 10 stations. The method for determining the sampling of station points in this study used the stratified random sampling method. Determination of the sample location points was done by dividing the sampling area into five classes based on the concentration of TSS Sentinel-2 TILE ID 48 M Imagery dated August 7, 2021. The sampling location points (Table 1) data were presented in Figure 1.

Table 1. Sampling station coordinate

Station	Longitude	Latitude
1	105° 48' 6"	5° 45' 1"
2	105° 48' 39"	5° 44' 46"
3	105° 48' 4"	5° 44' 46"
4	105° 49' 2"	5° 44' 26"
5	105° 47' 60"	5° 44' 18"
6	105° 48' 52"	5° 44' 5"
7	105° 48' 2"	5° 43' 51"
8	105° 47' 50"	5° 43' 31"
9	105° 48' 33"	5° 43' 27"
10	105° 49' 10"	5° 43' 29"

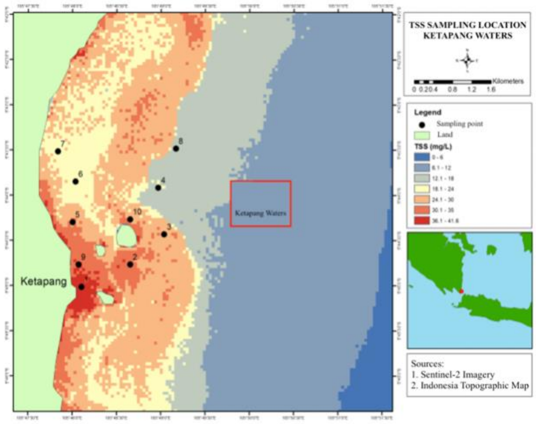

Figure 1. Sampling location

TSS Sample Collection and Processing

TSS Sampling and processing water sampling used 10 sample bottles. Risuana et al. (2017) suggested storing water samples in a cool box at <4°C to minimizes the microbiological decomposition of solids interfering with the TSS analysis process. TSS samples were then analyzed using the gravimetric method. The gravimetric method determines the suspended residue in the water test column gravimetrically, formulated according to SNI 6989.3.2019 (Indonesian National Standard).

$$TSS = \frac{(W_1 - W_0)x1000}{V}$$

Information:
TSS = Suspended Solids Load (mg/L)
W_0 = Weight of weighing media containing initial filter media
W_1 = Weight of weighing media containing filter media and dry residue (mg)
V = Volume of the test sample (mL)
1000 = Milliliter to conversion liter

Sentinel-2 Level 2A Imagery TSS Data Processing Method

The image data used in this study was Sentinel-2 level 2A imagery data. The data source was obtained through the website https://scihub.copernicus.eu/. The geometric correction stage in this study was not carried out because the Sentinel-2 level 2A imagery had been geometrically corrected. The channels used have been resampled, namely 10 m. Radiometric correction was not carried out on the Sentinel-2 level 2A satellite imagery because the level 2A product had been radiometrically corrected and had a Bottom-of-atmosphere reflectance value (Gatti & Bertolini, 2015).

The Normalised Difference Water Index (NDWI) process separates land and water by comparing the level of wetness in the Sentinel-2 imagery data (Hernoza et al., 2020).

This study uses the Laili and Jaelani algorithms to determine the TSS concentration value. The Laili (2015) and Jaelani (2016) algorithms were chosen because both successfully mapped TSS concentrations in waters with similar characteristics, including coastal areas that human activities affect. The Laili algorithm had the advantage of producing high accuracy on data with smooth spatial variations. In contrast, the Jaelani algorithm had been tested for its stability on image data with different turbidity levels. Both algorithms were based on the characteristics of TSS in Ketapang waters, making them optimal candidates for this study. While the algorithm used in Table 2.

Table 2. Algorithm

Algorithm	Equation
Laili	TSS= 31.42* (((Log(Rrs Green-Band)) / (Log(Rrs Red - Band)))-12.719
Jaelani	log(TSS)= 1,5212* (log (Rrs band blue)/log (Rrs band green)))-0,3698

Source: (Jaelani et al., 2016; Laili et al., 2015)

Image Data Validation

Validation of image and in-situ data was the final result of processing, which was used to determine the accuracy of the algorithm results according to in-situ sample data and image data. It was carried out using a regression equation.

Polynomial regression up to the third order was chosen because it balances accuracy and model complexity well. The third-order model was flexible enough to capture the non-linear patterns found in the TSS data but still avoided the risk of overfitting, which was more likely to occur at higher orders. Initial tests with linear and second-order models showed a lack of accuracy while increasing to higher orders did not significantly increase R^2 values, thus inefficient.

Linear regression : $y = a + bx$
Polynomial Order 2 : $y = a + bx^2 + cx$
Polynomial Order 3 : $y = a + bx^2 + cx^2 + dx$

Information:
y: Dependent variable
x: Independent variable
a, b, c, d, e: Regression coefficient

Calculating the error value in the data could reveal the validation value. The following equation could be used in the validation test of research data.

$$RMSE = \sqrt{\frac{\sum_{i=0}^{n}(Xm - Xe)^2}{n}}$$

Information:
RMSE = Root Mean Square Error
Xm = Measurement result value that was considered correct
Xe = Processed result value
n = Number of data

RESULTS

Total Suspended Solids (TSS) concentration measurements were conducted at ten sampling stations in Ketapang Waters. The TSS values obtained ranged from 17.26 mg/L to 22.90 mg/L, with the highest concentration found at Station 1 (22.90 mg/L) and the lowest concentration at Station 8 (17.26 mg/L) (Table 3).

Table 3. In-situ TSS concentration based on sampling coordinate

Stasiun	*Longitude*	*Latitude*	TSS (mg/L)
1	105° 48' 6"	5° 45' 1"	22.90
2	105° 48' 39"	5° 44' 46"	20.24
3	105° 48' 4"	5° 44' 46"	17.36
4	105° 49' 2"	5° 44' 26"	17.73
5	105° 47' 60"	5° 44' 18"	22.14
6	105° 48' 52"	5° 44' 5"	20.56
7	105° 48' 2"	5° 43' 51"	22.11
8	105° 47' 50"	5° 43' 31"	17.26
9	105° 48' 33"	5° 43' 27"	21.96
10	105° 49' 10"	5° 43' 29"	20.31

Generally, it tends to be higher at stations closer to the coastline and decreases towards deeper waters (Figure 2).

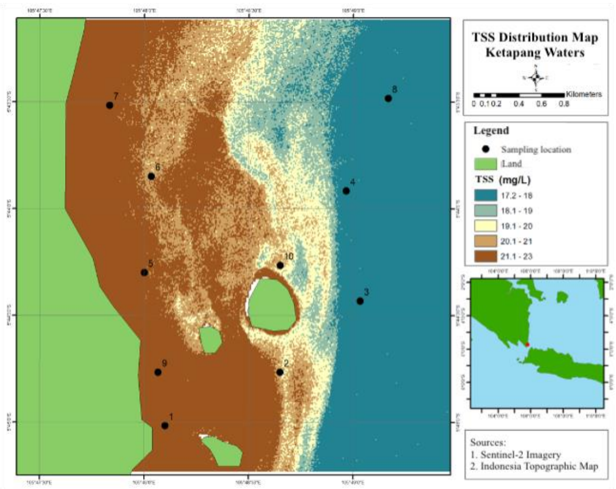

Figure 2. Distribution of TSS in Ketapang Waters

The evaluation of algorithm performance in predicting TSS distribution indicates that the Laili (2015) algorithm had a lower RMSE (0.639) compared to the Jaelani (2016) algorithm, which had an RMSE of 1.063. It suggests that TSS estimates produced by the Laili algorithm were closer to the field measurement values. Meanwhile, the coefficient of determination (R^2) for the Jaelani algorithm was higher (0.9905) compared to the Laili algorithm (0.9723). It indicates a very strong correlation between predicted results and observational data. Nevertheless, the Laili algorithm was more recommended as it provides estimates with lower error rates, making it more suitable for mapping TSS distribution in this aquatic environment (Table 4).

Table 4. RMSE

Algorithm	RMSE	R2
Algorithm of Jaelani (2016)	1.063	0.9905
Algorithm of Laili (2015)	0.639	0.9723

DISCUSSION

In-situ TSS Concentration

Laboratory tests using gravimetric analysis showed that the highest TSS concentration was at station 1, 22.90 mg/L, while the lowest was at station 8, 17.26 mg/L (Table 3). High TSS concentrations in coastal waters are influenced by various factors, including land-based sediment input, tidal movements, and anthropogenic activities (Ondara et al., 2021; Winnarsih et al., 2016).

Validation and Visualisation of TSS Distribution

The suitability between image data and TSS concentration from in-situ measurements was assessed using a polynomial regression approach. The TSS concentration data obtained from in-situ measurements were correlated with those derived from image data processing using different algorithms. The results of the polynomial regression analysis provide a coefficient of determination (R^2) value that indicates the strength of the relationship between the TSS concentration estimated from image data and the results of in-situ measurements. Table 4 shows that the Laili (2015) algorithm performed better by achieving an R2 at 0.9723 and a lower RMSE of 0.639. In contrast, the Jaelani (2016) algorithm had a slightly higher R2 value at 0.9905 but with a higher RMSE of 1.063. It indicates a greater prediction error. Both algorithms show a strong correlation with in-situ measurements, but the Laili (2015) algorithm is more effective in estimating the TSS concentration due to its lower RMSE value. The effectiveness of the polynomial regression model in improving the accuracy of TSS acquisition from satellite data, especially in the context of Ketapang Waters. Spectral bands in blue, green, and red are particularly responsive to the detection of TSS (Gantari, 2020; Permatasari, 2020).

The 3rd-order polynomial regression algorithm was the most effective model for determining TSS in Ketapang Waters. The equation model used was $y=-0.0228x^3+1.3401x^2-25.16x+170.08$ where x represents the calculation results from the Laili Algorithm. The 3rd-order polynomial regression equation was applied to these algorithm-derived values to visualize TSS concentration (Figure 2). This approach is effective in improving the estimation of TSS accuracy. It aligns with (Balasubramanian et al., 2020), who stated that higher-order polynomial regression better captures the non-linear relationship between spectral reflectance and TSS concentration.

The TSS distribution map (Figure 2), derived from Sentinel-2 imagery from September 26, 2022, shows TSS concentrations ranging from 17.2 to 23 mg/L. The spatial pattern indicates higher concentrations near the coastline, particularly at Stations 1, 5, 7, and 9, with respective values of 22.90 mg/L, 22.14 mg/L, 22.11 mg/L, and 21.96 mg/L. The high concentration of Total Suspended Solids (TSS) in coastal areas is influenced by various factors, including currents, tides, river discharge, and land cover, which contribute to increased sedimentation in coastal waters before gradually decreasing toward the open sea (Fathiyah et al., 2017; Wijayanti, 2020).

In contrast, lower TSS concentrations were observed at Stations 3, 4, and 8, with 17.36 mg/L, 17.73 mg/L, and 17.26 mg/L, respectively. These stations are located further from the coastline, where greater water depths limit sediment resuspension caused by currents and waves, reducing the number of suspended particles in the water column (Ma'arif & Hidayah, 2020). Furthermore, seawater dilution also contributes to the decrease in TSS concentrations because suspended particles are transported from the coast and gradually spread to the open sea, causing TSS concentration to decline as the distance from the coast increases (Miranda et al., 2021; Winnarsih et al., 2016).

Spatial variations in TSS distribution in Ketapang Waters reflect the influence of coastal geomorphology and human activities. Higher concentrations in nearshore areas are consistent with previous studies that found increased TSS levels in coastal waters due to river sedimentation and shoreline erosion (Prayoga & Barus, 2021). In line with (Nurfatimah et al., 2019), coastal waters are dynamic environments where sediments from land are frequently resuspended by waves and currents, increasing TSS concentrations in nearshore zones.

CONCLUSION

This study found that the Laili (2015) algorithm is better than the Jaelani (2016) algorithm in mapping the TSS distribution in Ketapang Waters, achieving a high R^2 value of 0.9723 and a lower RMSE of 0.639. The 3rd-order polynomial regression model derived from the Laili algorithm is represented by the equation $y=-0.0228x^3+1.3401x^2-25.16x+170.08$, providing a reliable estimate of TSS concentration. It indicates that this model is suitable for satellite-based water quality assessment.

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