Estimation of Chlorophyll–a and Total Suspended Solid Based on Observation and Sentinel-2 Imagery in Coastal Water Teluk Awur, Jepara-Indonesia

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Abstract
The existence of aquaculture in Marine Science Techno Park (MSTP), Jepara requires good-quality water. Remote sensing is the right solution to conduct routine, cost-effective, and wide-ranging monitoring. This study aims to estimate the Total Suspended Solid (TSS) and chlorophyll-a (Chl-a) values based on Sentinel-2 imagery. The reflectance values used are from Sentinel-2A (http://marine.copernicus.eu/acquisitions on 14 September and 30 October 2022). The TSS estimation algorithm used is a single band (red), while for Chl-a, it uses the sum of four visible bands namely blue, green, red, and near-infrared. The predicted TSS values from the Sentinel-2 ranged from 16.65-144.78 mg/L (average 44.59 mg/L) and Chl-a was 1.65-5.57 µg/L (average 3.35 µg/L) and 0.59 - 5.284 µg/L (average 2.49 µg/L) in September. While the TSS and Chl-a in-situ in October 2022, ranged from 48.80 - 78.20 mg/L (mean 55.81 mg/L) and 0.882 - 4.736 mg/L (average 3.10 mg/L). The performance of the algorithm used in this study is not suitable for implementation in this study regarding the low prediction error estimation values as follows: RMSE, bias, and MAPE values for TSS are 21.17 mg/L, -10.76, and 31.52%, respectively; and for Chl-a are 1.04 µg/L, 0.25, and 35.83%, respectively. Thus, a special algorithm needs to be developed for the coastal waters of Teluk Awur.

Keywords: Chlorophyll-a, MSTP, Sentinel-2, Suspended, Teluk Awur

1. Introduction

Anthropogenic activities on land can cause the degradation of coastal waters. Total Suspended Solids (TSS) and chlorophyll-a (Chl-a) are key parameters in water quality monitoring [1] [2] and [3]. Coastal waters around Marine Science Techno Park (MSTP) are located close to agricultural areas, aquaculture activities, and settlements. Thus, these activities will have an impact on increasing the input of pollutants, such as suspended sediments and organic matter residues. High levels of TSS can affect the turbidity of coastal waters. On the other hand, the presence of organic matter can increase nutrients, which in turn affects the high concentration of Chl-a, due to the development of phytoplankton. This will result in poor water quality as the main source of aquaculture media for pond management in MSTP and ecologically put pressure on ecosystems in coastal waters, such as seagrass and coral life.

Chl-a in the column of water can assess its trophic quality status [4] [5] and [6]. Chl-a is the main photosynthetic pigment of plants [1], and it can be used as an indicator of phytoplankton biomass and eutrophication of waters [4] and [5]. The presence of TSS can cause turbidity and reduce the intensity of light entering the water [1] and [4] and interfere with photosynthesis. TSS also serves as a source of nutrient input from land and causes waters to become more fertile [7], and areas with high anthropogenic activity have high fertility [8]. Continuous monitoring is important, related to management policies on the presence of aquaculture in MSTP and waste management. Monitoring water quality through continuous sampling is expensive and time-consuming [3] and [9]. Remote sensing can be used for routine and cost-effective monitoring [10]. Monitoring water quality is very important because it relates to the health status of an ecosystem [5]. So far, monitoring has been carried out in a traditional in-situ manner (through collecting water samples and further analysis in the laboratory) [11].

Continuous monitoring requires an expensive and long time. In the late 1970s, the sea color satellite mission was successful as a remote sensing technology that could observe water conditions regularly, locally and globally [12]. A time series compilation of historical data can be used to evaluate changes in water quality over time. However, this technology has weaknesses, because the resulting performance is highly dependent on the weather, changes in air masses, and sunlight conditions, which will directly affect the quality and quantity of useful data and require an appropriate algorithm.

TSS and Chl-a values in Semarang coastal waters based on Sentinel-3 imagery have been monitored [13]. However, the estimated Chl-a value based on Sentinel-3 images can only explain 50% of the field observation value. The algorithm used in Sentinel-3 is the algorithm from Moutzouris-Sidiris and Topouzelis et al., [11], which is thought to not be suitable for the characteristics and optical properties of coastal waters in Indonesia, especially Semarang coastal waters. Estimation of Chl-a with Moderate Resolution Imaging Spectroradiometer (MODIS) level-3 in the coastal waters of Semarang and Jepara, has also been carried out by Maslukah et al., [14], but there is a difference of five times higher observation data than data from MODIS images. MODIS level 3 is less suitable for coastal areas with a rather restricted area. The coastal waters have complex spectral colors due to the high presence of organic matter in the water. A high-resolution satellite is required to monitor the ever-changing dynamics of water quality on a spatial and temporal scale [5] and [6]. The Sentinel-2 has the benefit of carrying 13 spectral channels that range from Visible and Near Infrared (NIR) to Short-Wave Infrared with a higher resolution of 10m. Monitoring of water quality (Chl-a, TSS, and turbidity) using Sentinel-2 has been done by several researchers, such as [2] [5] [6] [15] [16] and [17]. Shaik et al., [2] have recommended that the use of Sentinel-2 is more suitable for Chl-a measurements in coastal waters. In Indonesia, the improvement of the Sentinel-2 algorithm has not been extensively performed. While the Landsat image algorithm has been extensively improved by several researchers [12] and [18].

The results of Qanita et al., [19] in Semarang waters using Sentinel-2, for TSS and Chl-a observations (in-situ), using the C2RCC algorithm did not coincide with actual field conditions. Furthermore, Wirasatriya et al., [20] have developed a special algorithm for monitoring TSS in the BKB-Semarang estuary based on Sentinel-2 images. The use of Sentinel-2 is related to its higher spatial resolution, which is 10m. Based on these studies, it is necessary to conduct research on the estimation of TSS and Chl-a based on Sentinel-2 images and determine the difference in the value of field observations in the coastal waters of Teluk Awur and its surroundings.

This study estimates chlorophyll-a and TSS concentrations using Sentinel-2 imagery using algorithms developed by Maslukah et al., [21] for Chl-a and Wirasatriya et al., [20] for TSS. The results of this study are expected to be taken into consideration in the use of remote sensing in water quality monitoring, especially for TSS and Chl-a parameters.

2. Materials and Methods

This research was conducted in MSTP coastal waters in Teluk Awur, Jepara. The research locations are presented in Figure 1. Sampling was carried out on September 14, 2022 (at 14 stations) and October 30, 2022 (at 53 stations). Sentinel 2A image data is downloaded from http://marine.copernicus.eu/ on the same day as the sampling date.

2.1 Chlorophyll-a (Chl-a) Analysis

We adopted the method of Chl-a analysis from APHA [22]. Filtering was carried out for 1 liter at each station, using nitrocellulose filter paper (Millipore, 0.45 m). MgCO3 has added 3 drops to the sample to prevent acidification during filtering. The filtrate was extracted with 10 ml of 90% acetone, and incubated for 12-16 hours in a refrigerator. Centrifugation was carried out at 4000 rpm for 5-10 minutes, and the top was poured into a cuvette (1cm) and absorbance values were read at 750 nm, 664 nm, 647 nm, and 630 nm using an Optima UV-Vis spectrophotometer. The chlorophyll-a value on the cuvette was calculated using Equation 1 [22], followed by the estimation of Chl-a using Equation 2.

$$C_a = 11.85\lambda_{664} - 1.54\lambda_{647} - 0.08\lambda_{630}$$

Equation 1

Remarks:

C_a: concentration Chl-a in the cuvette (µg/mL);
λ_{664}, λ_{647}, λ_{630} are spectrophotometer wavelength.

$$Chl - a\,[\frac{mg}{cm^3}] = \frac{C_a \times Extract\ volume\,[ml]}{Volume\ of\ \ sample\,[L]}$$

Equation 2

Remarks:

Ca: chlorophyll-a concentration in the cuvette

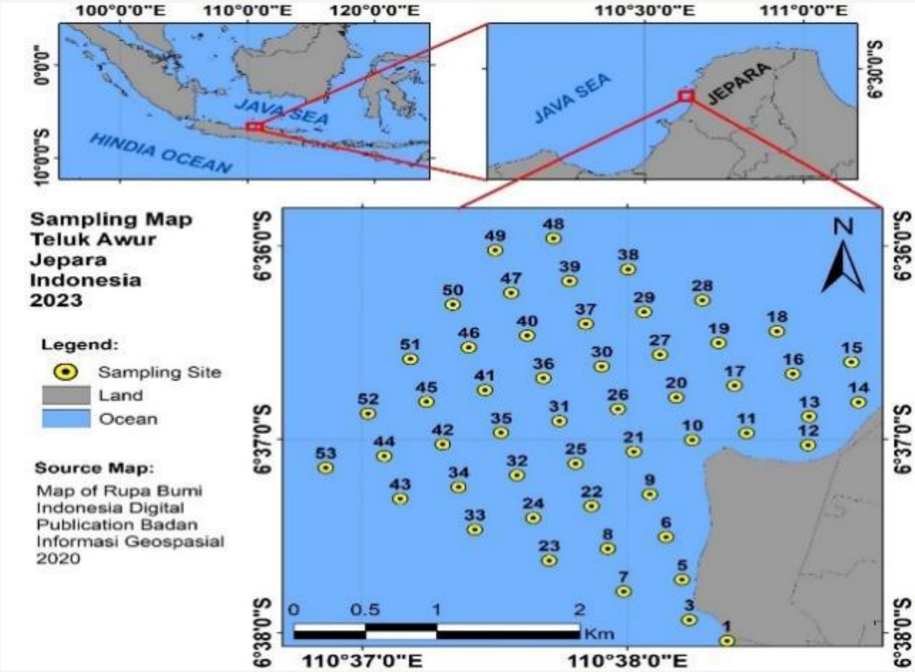

Figure 1: Location of sampling

2.2 Total Suspended Solids (TSS) Analysis

A total of 500 ml of water samples were filtered using GF/F paper (pore size 0.7 µm). TSS is calculated by subtracting the final weight from the initial filter weight for each sample.

2.3 Estimation of TSS and Chl-a Based on Sentinel-2 Images

In estimating Chl-a with Sentinel-2, this study uses an algorithm that has been formulated from previous research by Maslukah et al., [21], following Equation 3. The estimation was calculated using reflectance data from visible and near-infrared (NIR) bands with 10m resolution. For Sentinel-2 imagery, the characteristic wavelengths in the blue (B2), green (B3), red (B4), NIR (B8), and NIR (B8a) bands are 492.4 nm, 559.8 nm, 664.6 nm, 832.8 nm, and 864 nm, respectively [23]. All bands are 10m resolution, except B8a, which is the NIR Band with 20m spatial resolution.

$$Chl-a = 10^{0.273-0.725cB2-0.625cB3+1.623cB4+0.809cB8}$$

Equation 3

Where:

B2, *B3*, *B4*, *B8*: band of blue, green, red, near infrared

B8a: *NIR* band

c: the ratio of *B8/B8a*

Furthermore, the data is processed using SNAP software for correction, masking, and cropping according to the research area to make it easier to render. While the algorithm used for TSS estimation follows formula 4, which has been developed by Wirasatriya [20] from BKB Semarang waters, namely using the red band (B4).

$$TSS = 1956.2B4 - 50.056$$

Equation 4

2.4 Data Analysis

The regression and correlation analysis that we carried out aimed to determine the significance of the relationship between the two variables, i.e., TSS and Chl-a. We also estimate the error values of TSS and Chl-a from satellite estimations on observational data using the root-mean-square error (RMSE), bias, and mean absolute relative error (MARE) as follows in Equations 5, 6, and 7. The prediction and observation data that we obtained then visualized the distribution patterns using interpolation methods.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(Chla_{i,insitu} - Chla_{i,retr}\right)^2}{N}}$$

Equation 5

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$$BIAS = \frac{1}{N}\sum_{i=1}^{N}\left(Chla_{i,retr} - Chla_{i,insitu}\right)$$

Equation 6

$$MARE = \frac{100}{N}\sum_{i=1}^{N}\frac{\left|Chla_{i,insitu} - Chla_{i,retr}\right|}{Chla_{i,insitu}}$$

Equation 7

where $Chla_{i,insitu}$ and $Chla_{i,retr}$ refer to the observation and retrieved (estimation) Chl-a respectively; and N is the total of samples.

2.5 The Regression Model of Chl-a Versus TSS

The Chl-a is a proxy for phytoplankton and has a contribution as a constituent of TSS. The relationship between the two variables can be described through a regression equation model. Regression model analysis was conducted using IBM SPSS Statistics V21.0. The hypotheses in this study are H_0 (null hypothesis) and H_1 (alternative hypothesis). H_0 explains that Chl-a significantly contributes to TSS and H_1 is Chl-a does not significantly contribute to TSS. If $p<0.05$, then Ho is accepted and H_1 is rejected.

2.6 Spatial Distribution of TSS and Chl-a

The values of TSS and Chl-a, both insitu and estimated, are depicted in the distribution pattern map using the interpolation method. With interpolation, it is possible to predict the cell values at locations that experience a rare number of sample points. The interpolation method used is IDW (Inverse Distance Weighted), which is a method with the principle of point-to-point interpolation based on a linear-weighted combination function. This function is based on the distance, point value, and position of the interpolation cell.

3. Results and Discussion

3.1 Estimation of TSS and Chl-a from Estimation Sentinel-2

The TSS and Chl-a are important key water quality parameters whose monitoring can be estimated using satellite imagery by transforming algorithms capable of converting pixel values into estimated values for TSS and Chl-a concentrations. Phytoplankton is micro-autotrophs that play a major role in primary production and oxygen generation in aquatic systems [24]. However, toxic cyanobacteria blooms or excessive blooms caused by human activities cause environmental problems that directly affect a decrease in water quality and indirectly limit the use of water such as for cultivation media, fishing grounds, and swimming areas. The presence of phytoplankton in the waters can be estimated by measuring Chl-a [2] [6] [12] and [13].

According to the study, the in-situ for Chl-a and TSS on October 30, 2022 was in the range of 0.882 - 4.736 µg/L (average 2.903 µg/L) and 48.80 - 78.20 mg/L (average 55.81 mg/L), and the estimated satellite Sentinel-2 was between 1.65–5.57 µg/L (average 3.35 µg/L) and 16.65-144.78 mg/L (average 54.72 mg/L). On September 14, 2022, in-situ Chl-a was in the range of 3.3-5.9 µg/L (average 3.27 µg/L) and estimation 0.59-5.28 µg/L (average 2.49 µg/L). Full results per station are presented in Table 1.

3.2 The Regression Model Chl-a and TSS

The growth of phytoplankton in the water contributes to the increase in turbidity and suspended solids (TSS). There is a relationship between TSS and Chl-a phytoplankton that can be estimated based on Chl-a. A very high of TSS may inhibit the growth of phytoplankton due to light limitation. So these two variables are important to monitor and observe. The relationship between the two parameters can be analyzed based on the regression model [11]. The results of the analysis include the coefficient of determination (model summary), the significance value (Anova), and the coefficient values, which are presented respectively in Table 2, Table 3, and Table 4. Based on Tables 2 and 3, the relationship model between TSS and Chl-a has a coefficient of determination of 0.415 (in-situ, p=0.062) and 0.300 (estimation, p=0.148).

3.3 Validation of In-Situ and Predicted Data

The performance of Sentinel-2 in estimating water quality parameters (TSS and Chl-a) can be determined from the bias, RMSE, and MARE. Based on the algorithm developed by Wirasatriya et al., [20], with the red band, the TSS values range from 16.65 to 144.78 mg/L (average 44.59 mg/L). The resulting value is lower than estimation (Tabel 1). The bias calculation value of TSS obtained is -10.77, RMSE (21.17 mg/L), and MARE (31.52%) (n=50). Meanwhile, the Chl-a is in the range of 1.65-5.57 µg/L with an average value of 3.35 µg/L. The bias value was obtained as -0.25, RMSE (1.04 µg/L) and MARE (35.83%) (n=22). The scatter plot between the estimation and the in-situ data is shown in Figure 2.

3.4 Spatial Distribution of TSS and Chl-a from Observation (Insitu Data) and Estimation

Using an algorithm from previous research by Maslukah [21] in BKT waters, the estimated distribution pattern of Chl-a in the waters around MSTP, Jepara, and its surroundings on September 14, 2022 and October 30, 2022 is presented in Figure 3. The spatial distribution can be described using the IDW interpolation method. Figure 3 shows the in-situ and the estimation of the spatial distribution of TSS and Chl-a observations on September 14, 2022 and October 30, 2022.

Table 1: The concentration of Chl-a and TSS

No	TSS (mg/L)		Chl-a (µg/L)				No	TSS (mg/L)		Chl-a (µg/L)			
	October		October		September			October		October		September	
	In-situ	Predic-tion	In-situ	Pre-diction	In-situ	Pre-diction		In-situ	Predic-tion	In-situ	Predic-tion	In-situ	Predic-tion
1	78.20	144.78	-	-	-	-	28	54.00	41.69	-	-	-	-
3	71.00	106.44	-	-	-	-	29	56.60	61.45	-	-	-	-
5	52.60	91.77	0.88	1.92	0.70	1.61	30	59.20	37.78	3.35	2.36	-	-
6	52.00	65.95	-	-	-	-	31	51.40	35.63	2.63	2.93	1.95	2.60
7	53.60	37.19	-	-	-	-	32	55.80	47.36	3.53	3.16		
8	53.80	32.30	3.31	1.65	-	-	33	51.20	31.71	-	-	-	-
9	54.80	34.26	-	-	2.47	3.05	34	53.60	35.63	-	-	-	-
10	55.60	46.38	3.14	3.80	-	-	35	53.60	43.45	4.04	4.82	-	-
11	53.80	34.45	-	-	-	-	36	53.00	51.28	3.28	2.97	4.04	2.60
12	55.00	26.63	4.74	3.38	-	-	37	71.60	47.36	2.38	3.40	-	-
13	54.40	26.24	-	-	8.43	5.28	38	50.60	64.38	3.60	5.57	-	-
14	56.00	55.97	3.17	3.04			39	54.60	62.23	-	-	-	-
15	54.80	16.65	0.93	2.37	4.80	2.98	40	52.60	37.19	-	-	-	-
16	56.60	35.63	-	-	-	-	41	58.80	47.17	-	-	-	-
17	-	-	3.60	2.17	-	-	42	60.80	39.15	-	-		
18	56.60	46.38	4.44	1.66	4.44	1.66	43	54.20	34.06	-	-	0.52	0.59
19	53.00	23.89	-	-	6.67	2.94	44	51.80	37.39	-	-	-	-
20	53.00	37.39	3.38	4.02			45	53.00	30.93	-	-	-	-
21	56.60	37.78	-	-	4.78	4.37	46	56.40	31.71	-	-	-	-
22	63.40	40.52	2.51	4.44	1.16	1.66	47	58.40	42.28	-	-	-	-
23	54.00	40.12	-	-	-	-	48	74.60	65.75	-	-	0.58	1.66
24	51.40	43.65	-	-	-	-	49	53.60	49.51	1.99	1.79	-	-
25	51.40	48.54	-	-	-	-	50	58.60	47.36	-	-	0.88	0.85
26	50.80	34.06	3.16	3.72	-	-	51	55.60	35.04	4.59	4.45	-	-
27	54.60	44.04	3.16	3.95	-	-	52	55.80	31.91	3.50	3.12	4.31	2.79
							53	54.40	38.17	-	-	-	-

- *No data*

Table 2: Model Summary of TSS to Chl-a relationship

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1 (in-situ)	.415[a]	.172	.128	.90058
2 (estimation)	.300[a]	.090	.042	1.02726

a. Predictors: (Constant), TSS

b. Dependent Variable: Chl-a

Table 3: ANOVA model relationship of TSS to Chl-a

Model		Sum of Squares	df	Mean Square	F	Sig.
1 (in-situ)	Regression	3.200	1	3.200	3.945	.062[b]
	Residual	15.410	19	.811		
	Total	18.610	20			
2 (estimation)	Regression	1.978	1	1.978	1.874	.187[b]
	Residual	20.050	19	1.055		
	Total	22.028	20			

a. Dependent Variable: Chl-a
b. *Predictors: (Constant), TSS*

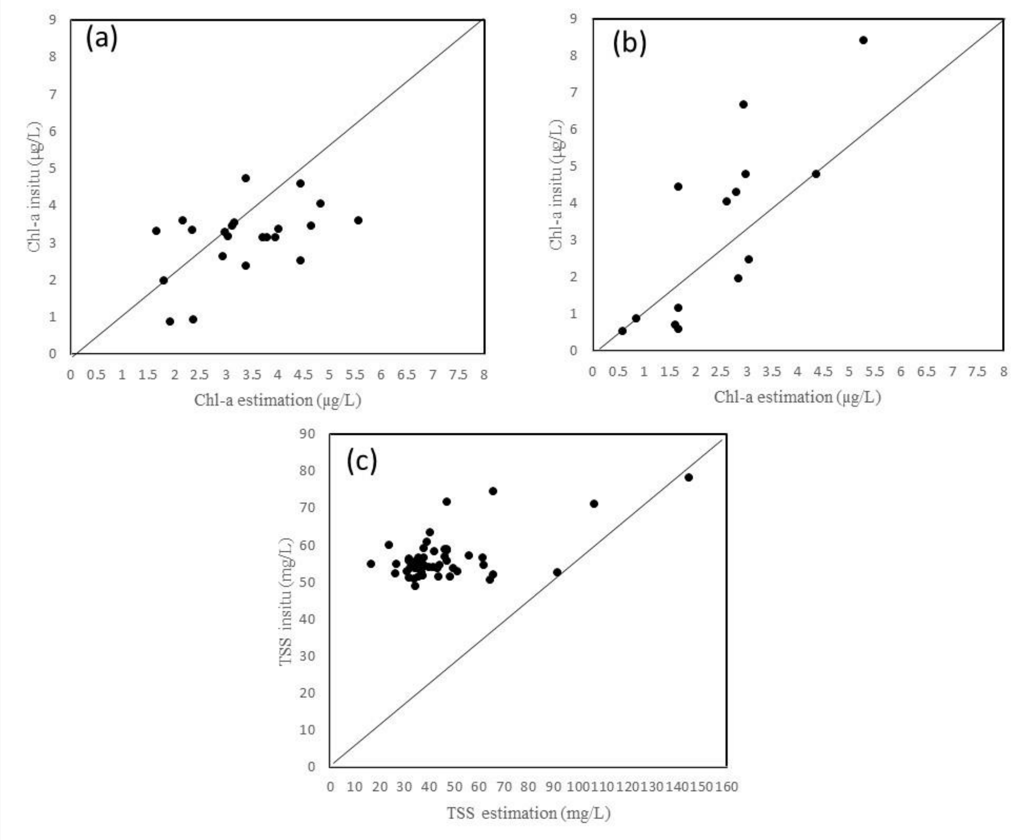

Figure 2: Validation of estimated Chl-a (a) 30 October 2022 (b) 14 September 2022 and (c) TSS in October 2022

4. Discussion

This study estimates Chl-a and TSS values using remote sensing technology. The use of Sentinel-2 level 2A imagery was trialed for site monitoring in narrow coastal waters, due to its resolution. The estimation of TSS and Chl-a used an empirical formula from Semarang coastal waters, based on reflectance values of visible and NIR bands with 10m resolution. The results showed that the performance of Sentinel-2 level 2A using the algorithms of Maslukah et al., [21] for Chl-a and Wirasatriya et al., [20] could not be explained very well for the coastal waters of Teluk Awur. This study is different from other studies, related to the band used. Research by Ouma [25] estimated chl-a in reservoir waters using the green band and SWIR-1 (B11), which used a second-order polynomial algorithm model and a combination of bands with 10 and 20 m spatial resolution. According to the algorithm of Semarang coastal waters, the predicted Chl-a on September 14, 2022 ranged from 0.59-5.28 µg/L (average 2.49 µg/L) and on October 30, 2022 ranged from 1.65-5.57 µg/L (average 3.35 µg/L). Meanwhile, the TSS ranged from 16.65-144.78 mg/L (average 54.72 mg/L).

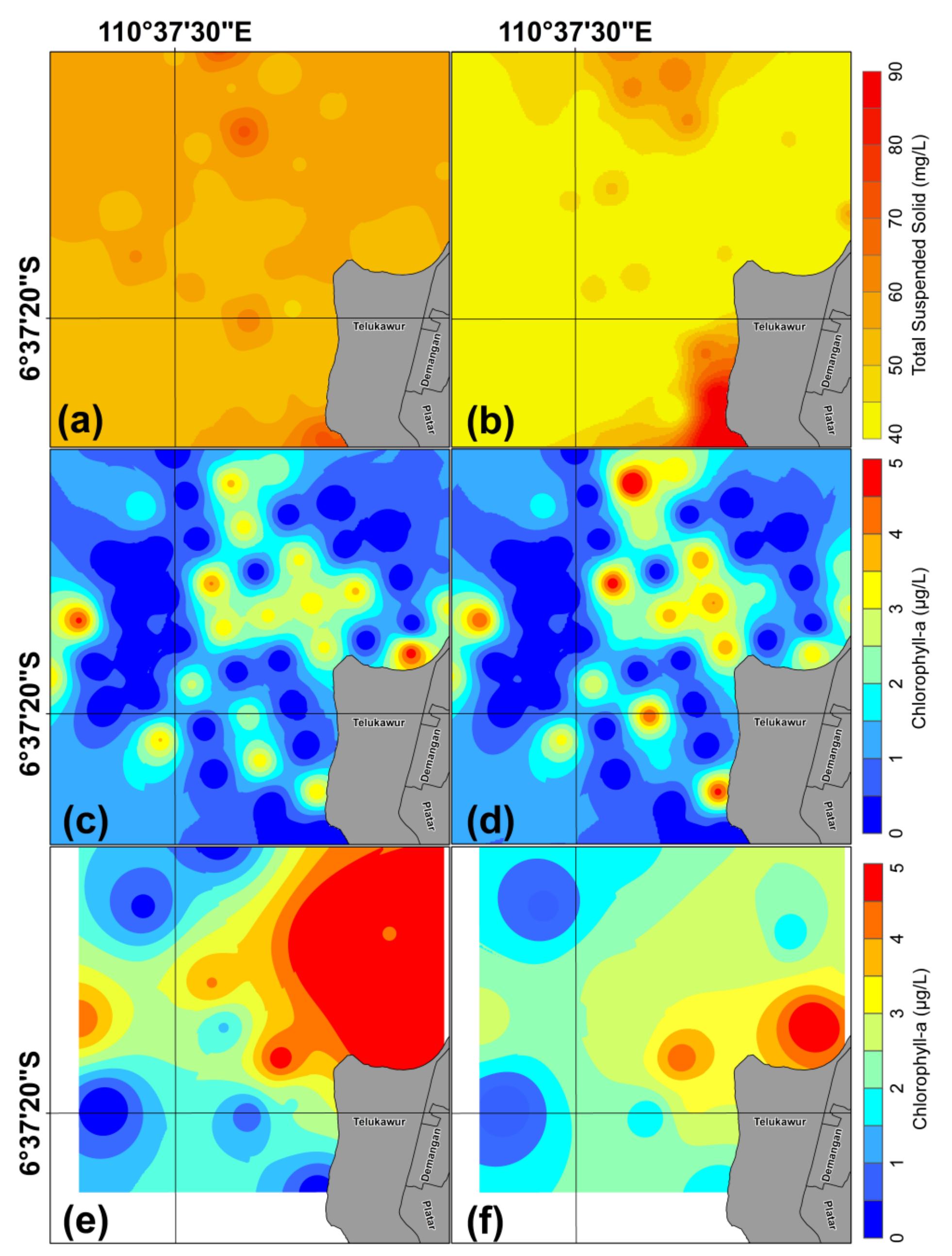

Figure 3: Spatial distribution of (a) TSS in-situ (b) TSS estimation, (c) Chl-a in-situ, (d) Chl-a estimation on October 30, 2022 and (e) Chl-a in-situ, (f) Chl-a estimation on September 14, 2022

Furthermore, the mean of observed (in-situ) Chl-a was 3.27 µg/L on September 14, 202 and 2.93 µg/L on October 30, 2022, while in-situ TSS was 55.81 mg/L. In this study, we analyzed the performance of Sentinel-2 level 2A (using algorithms from Semarang coastal waters) based on the values of R^2, bias, RMSE, and MARE with values of 0.33 (R^2), -10.77 (bias), 21.17 mg/L (RMSE), and 31.52% (MARE) for TSS and 0.23 (0.65), 0.25 (-0.77), 1.04µg/L (1.75µg/L) and (35.83%) (51.48%) in October (September). Based on this value, it shows that the performance of the algorithm is not perfect. Katlane et al., [5] obtained an R^2 value with Sentinel-2 for Chl-a of 0.7, which in their study, used the B5/B4 ratio algorithm, where B5 is a band with a spatial resolution of 20m.

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In this study, only the band with 10m spatial resolution was used. Meanwhile, Bramich et al., [23] using a single band (NIR/705nm) obtained an R^2 value of 0.9.

There are interesting features in the temporal distribution (Figure 2), which is based on the average value, Chl-a has a different pattern between September and October. In September, the in-situ Chl-a values were greater than the estimation, and conversely, in October, the in-situ Chl-a values were lower than the estimation. This is related to the seasonal differences when sampling in the field. Alifdini et al., [26] explained that September to November is the transition season (summer to rainy season), and rain intensity is higher in November. This will have an impact on high TSS values due to run-off [27]. The presence of high TSS in the water can interfere with the photosynthesis process, and the development of phytoplankton decreases (characterized by a decrease in Chl-a) [1].

Based on Figure 3, we found that there is a similar pattern of in-situ and predicted Chl-a in September and October 2022. Meanwhile, the analysis of the relationship between the in-situ Chl-a data and the estimation based on the function of the measuring station shows that the estimation is not always consistent throughout the island area of Teluk Awur, except for the Chl-a in September, which is more consistent, which in the study can be shown from Figure 2. For future research, it is necessary to develop a new algorithm that is generated from a special area of Teluk Awur coastal waters by using a suitable ratio of multiple bands. The use of a 20-m, and 60-m resolution band or combination with 10m at Sentinel-2 level 2A also needs to be simulated in the study area.

5. Conclusion

The estimation of the TSS and Chl-a values from Sentinel 2 imagery using an equation from Semarang coastal waters on October 30, 2022 ranges from 16.65-144.78 mg/L (average 44.59 mg/L) and 1.65-5.57 (average 3.35 µg/L). While the in-situ data is in the range of 48.80 - 78.20 mg/L (average 55.81 mg/L) and 0.882 - 4.736 µg/L (average 2.903 µg/L). The performance of the TSS (Chl-a) algorithm used in this study is not suittable for implementation. The RMSE, bias, and MAPE values for TSS were 21.17 mg/L, -10.76, and 31.52%, and Chl-a were 1.04 µg/L, 0.25, and 35.83%, respectively. The values of TSS and Chl-a using Sentinel-2 on October 30, 2022 are underestimated for TSS and overestimated for Chl-a. The use of 10m spatial resolution on Sentinel-2 in Teluk Awur is perform well. Estimation Chl-a needs to consider the use of band ratio and combine it with other resolution bands. While TSS needs to be generated so as to get a specific constant value that can describe the condition of the coastal waters of Teluk Awur.

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