Distribution of phytoplankton using remote sensing in Cimandiri Estuary, Sukabumi, West Java

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Abstract. Estuaries are coastal ecosystems with highest productivities owing to the presence of phytoplankton in water. Phytoplankton plays a key role in water as a primer for productivity, primarily by producing both organic and inorganic substances. In 2010, the construction of Pelabuhanratu Coal Power Plant (PLTU) along the banks of the Cimandiri estuary got completed and PLTU started operating. This study aims to analyze the changes and relation between the water’s physical characteristics and the phytoplankton distribution before and after the construction of the Pelabuhanratu PLTU. Variables used total suspended solids, salinity, sea surface temperature, currents, and chlorophyll-a concentration to describe the water’s physical characteristics as well as indicators for the presence of phytoplankton. These methods were combined with remote sensing data and validated by in-situ results. The results indicate that the amount of phytoplankton before the construction of PLTU was significantly higher in comparison with that after the completion of PLTU. Moreover, phytoplankton concentration is directly proportional to the total suspended solids and sea surface temperature but is inversely proportional to salinity, and has no effect on ocean currents.

Keywords: Chlorophyll-a, estuary, landsat, phytoplankton, spatial analysis

1. Introduction
Coastal areas have a wide variety of ecosystems such as the estuary ecosystem. Estuaries are semi-enclosed water bodies affected by both the mixing of and rise and fall of the sea and fresh water from continental sources. The presence of freshwater streams, which occur inland and continue to the coast, and water movement processes due to the tidal currents, which transport minerals, organic matter, and sediments, are responsible for the high productivity of estuary water.

In estuaries, the presence of phytoplankton increases the productivity of water. Phytoplankton is photosynthetic marine microorganisms that drift freely in the ocean [1]. Phytoplankton plays a primary role in aquatic productivity by producing organic and inorganic substances through photosynthesis. Phytoplankton contains photosynthetic pigments such as chlorophyll-a, which weighs approximately 1–2 % of the dry weight of algae [2]. Both phytoplankton and autotrophic organisms contain chlorophyll-a pigment, which is directly involved in photosynthetic processes in the form of an active pigment.

By the end of 2010, the development and construction of the Pelabuhanratu Coal Power Plant (PLTU), on the edge of Cimandiri estuary, was completed. The Cimandiri Estuary is located in Pelabuhanratu Bay, Sukabumi West Java. Pelabuhanratu Bay is the largest bay along Java’s southern coast.
coast. With an area of approximately 86.20 Ha, the PLTU is located on the northern side of the Cimandiri estuary.

The development of the steam power plant had a direct impact on the aquatic environment within the Cimandiri estuary. This study uses remote sensing technology to analyze and discuss the change in the phytoplankton distribution and water’s physical characteristics before and after the construction of the PLTU in the Cimandiri estuary.

2. Experimental

The physical characteristics of water, i.e., suspended solids, salinity, sea surface temperature, ocean currents, and the concentration of chlorophyll-a were temporally investigated before the construction of the Pelabuhanratu steam power plant in 2006 and after construction in 2016. We determined phytoplankton distribution abundances using remote sensing image analysis as well as remote sensing validation via in-situ measurements.

This study uses temporal datasets from the Landsat 5 TM image database before PLTU construction in 2006 and the Landsat 8 OLI image database after PLTU construction in 2016 and 2017. Image data in 2006 and 2016 were divided into wet and dry months based on the Oldeman classification [3]. For each period, one image was selected that satisfied the condition of less than 10% cloud cover.

Landsat 5 TM and 8 OLI image data were processed using an algorithm to calculate variable values, such as chlorophyll-a, suspended sediment, temperature, salinity, and current direction from Ocean Surface Current Analysis-Real Time data. We conducted sample measurements directly during a field survey to obtain in-situ values to validate image data processing results.

We processed image data by transforming image values, previously corrected and calibrated, to determine variable values such as chlorophyll-a, suspended sediment, sea surface temperature, and salinity. Using math band function, we transformed and processed the initial image data by placing formulas, in the form of algorithm values, into the image. Here, we use the following algorithm formulas to determine the values of the variables:

a. To determine the value of chlorophyll-a [4]:
\[
C = 0.2818 \times \left( \frac{\text{Band 4} + \text{Band 5}}{\text{Band 3}} \right)^{\lambda,497} \tag{1}
\]

b. To determine the temperature:
\[
T = \frac{K_2}{\ln \left( \frac{K_1}{L} + 1 \right)}
\]

c. To determine the value of the total suspended solids (TSS) [5]:
\[
\text{TSS (mg/l)} = 8.1429 \times \exp \left( 23.704 \times \text{Band 4} \right) \tag{2}
\]

d. To determine the value of salinity [6]:
\[
\text{Salinity} = 29.983 + 165.047 \, (\text{B2}) - 260.227 \, (\text{B3}) + 2.609 \, (\text{B4}) \tag{3}
\]

Field measurements for salinity, sea surface temperature, and chlorophyll-a concentration were used to perform a validation test with the results from the image processing using the root mean square error (RMSE) statistical test [7] with the following equation:
\[
\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{n}} \tag{4}
\]

\( P_i = \) Value of the predicted model \( O_i = \) Value of observation result

The model is considered accurate when the value of RMSE is between 0 and 1. Large RMSE values indicate a decrease in the accuracy of the model, whereas values near 0 are more accurate [8].
3. Results and discussion

3.1. The physical characteristics of water and phytoplankton distribution before the construction of PLTU

In Pelabuhanratu, the distribution of chlorophyll-a and the suspended solids, salinity, and sea surface temperature before the construction of the PLTU during wet months have a higher concentration or value, respectively, in comparison with that in the dry months. Wet and dry months exhibit patterns of chlorophyll-a distribution that have high values at the outlet of the Cimandiri estuary of its concentration. In the dry months of 2006, we observe that patterns for chlorophyll-a distribution values did not have broad and high values in comparison with that during the wet months of 2006 (figure 1 and figure 2).

Generally, the results indicate that chlorophyll-a distribution, suspended solids, and salinity will appear to have the similar distribution patterns: values for chlorophyll-a, and suspended solids increase toward the west and decrease toward the southwest, whereas salinity increases toward the west and south-west. For sea surface temperature values, higher values exist along the coast. The values of these variables during the wet and dry months before the development of the PLTU are similar. Chlorophyll-a values are proportional to the suspended solids and sea surface temperature values and are inversely proportional to salinity values, whereas sea surface current has no visible influence.

3.2. The physical characteristics of water and phytoplankton distribution after the construction of PLTU

The distribution of chlorophyll-a and physical characteristics of waters, such as suspended solids, salinity, and sea surface temperature are different after the construction of PLTU in comparison with the characteristics before construction. This difference occurs because the chlorophyll-a and physical

Figure 1. Map of chlorophyll-a, and the physical characteristics of water before the construction of the PLTU in wet months during 2006.
characteristics of the water experienced changes in concentration due to the coal-fired steamer docks located north of the Cimandiri estuary, which indirectly causes changes in water flow patterns throughout the Cimandiri estuary.

In 2016 dry and 2017 wet seasons (figure 3 and figure 4) patterns for chlorophyll-a, salinity, and the suspended solids increase toward the west and decrease toward the southwest. The sea surface temperature has the highest values along the northern shoreline and sea surface current variables have no effect.

3.3. Validation test
The data used to test the validity are the values of the chlorophyll-a concentration, salinity, and sea surface temperature from the Landsat image processing 8 acquired on March 13, 2017, and in-situ measurement data taken on January 24, 2017. We did not use the 2006 image processing results because the time gap is too long based on when the field data was taken. However, the results for this test are still capable of depicting the level of accuracy of the 2006 data because we used identical images and formula algorithms. The results of the landscape image data processing and in-situ measurements are listed in table 1.

The validation results show that the image processing RMSE values from field data are 0.527 for chlorophyll-a, 0.155 for salinity, and 0.112 for temperature. The RMSE value for each of these variables indicates that a positive relation exists between the two datasets. The algorithm results meet the specified tolerance. Therefore, we conclude that the overall values of the variables used in this study represent the conditions and actual concentrations in the estuary.
Figure 3. Map of chlorophyll-a, and physical characteristics of water after the construction of the PLTU in the wet months of 2017.

Figure 4. Map of chlorophyll-a, and physical characteristics of water after the construction of the PLTU in the dry months of 2016.
Table 1. A comparison of the data for field results and the image processing data.

| Sample | Coordinate | Chlorophyll-a (mg/m³) | Salinity (%) | Sea surface temperature (°C) |
|--------|------------|-----------------------|--------------|-----------------------------|
|        | Longitude  | Latitude              | In-situ value | Image value | In-situ value | Image value |
| 1      | 106.5312   | -7.0138               | 0.10         | 0.04       | 30           | 27.65       | 29.00       | 28.79       |
| 2      | 106.5313   | -7.0178               | 0.09         | 0.05       | 33           | 27.50       | 31.20       | 28.63       |
| 3      | 106.5313   | -7.0219               | 0.01         | 0.10       | 25           | 24.22       | 29.00       | 28.34       |
| 4      | 106.5278   | -7.0255               | 0.03         | 0.14       | 24           | 22.82       | 29.40       | 28.25       |
| 5      | 106.5242   | -7.0291               | 0.15         | 0.12       | 23           | 22.40       | 29.10       | 28.28       |
| 6      | 106.5241   | -7.0353               | 0.08         | 0.09       | 26           | 24.51       | 30.50       | 28.41       |
| 7      | 106.5278   | -7.0390               | 0.15         | 0.29       | 26           | 21.00       | 31.00       | 28.64       |
| 8      | 106.5313   | -7.0427               | 0.12         | 0.08       | 29           | 25.55       | 30.90       | 28.54       |
| 9      | 106.5349   | -7.0463               | 0.05         | 0.09       | 30           | 24.24       | 31.00       | 28.57       |
| 10     | 106.5387   | -7.0500               | 0.11         | 0.05       | 24           | 27.55       | 30.01       | 28.58       |

4. Conclusion

In this study, we demonstrated that chlorophyll-a concentration can be used as an indicator for the presence of phytoplankton in the Cimandiri Estuary. Higher chlorophyll-a concentration was observed at the outlet of the Cimandiri, which decreased with an increase in the distance from the outlet. Based on the results of this study, we observe that the high chlorophyll-a concentrations are directly proportional to the suspended solids and sea surface temperature values but are inversely proportional to salinity, and do not appear to be affected by the direction and speed of sea currents. Higher concentrations of chlorophyll-a are present in water characterized by high suspended solids and sea surface temperatures, whereas this water has lower salinity values. Before the construction of the PLTU, the chlorophyll-a concentration was higher and spread from the outlet of the Ci Mandiri, whereas, after the construction of the PLTU, chlorophyll spread further toward the south and southwest due to water flow obstruction caused by the Pelabuhanratu Power Plant pier. If we compare the conditions during the wet and dry months before and after the construction of the PLTU, we can see that wet month have higher values of chlorophyll-a in comparison with dry months.

References

[1] Nybakken J W and Eidman H M 1988 Biologi Laut: Suatu Pendekatan Ekologis (Jakarta: PT Gramedia Pustaka Utama)
[2] Realino B et al. 2005 Peningkatan Informasi Daerah Penangkapan Ikan Melalui Integrasi Teknologi Inderaja Pemodelan Hidrodinamika dan Bioakustik (Jakarta: Brok-Seacorn)
[3] Oldeman L R 1975 An agroclimate Map of Java and Madura (Bogor: Central Research Institute for agriculture)
[4] Wibowo A, Sumartono B, Setyantini W H and Populus J 1994 Remote Sensing and Geographic Information System 16-17
[5] Budhiman S, Hobma T and Vekerdy Z 2004 The Thirteenth of OMISAR 5 1-14
[6] Supriatna L, Supriatna J and Koetsor R H and Takarina D 2016 AIP Conf. Proc. 1729 020079
[7] Deus R et al. 2013 Ecol. Model. 253 28-4
[8] Chai T and Draxler R R 2014 Geosci. Model Dev. 7 1247-50