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Comparative Analysis of Rrs486 and Rrs551 Wavelength Effectiveness from SNPP_VIIRS Satellite Imagery for Chlorophyll-a Mapping in Madura Strait, East Java

Diyah Ayu Apriliana^a, Hendrikus Yuliano M.^b, Hendrata Wibisana^{c*}

Civil Engineering Department, University of Pembangunan Nasional Veteran Jawa Timur, Surabaya, Indonesia

E-mail: ^adiyahayu@upnjatim.ac.id , ^bhendrikusyuliano@upnjatim.ac.id , ^chendrata.ts@upnjatim.ac.id

*Corresponding author: hendrata.ts@upnjatim.ac.id | Phone number: +628165451697

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Abstract

This study assesses the comparative performance of two remote sensing reflectance (Rrs) wavelengths, Rrs486 and Rrs551, derived from Suomi NPP VIIRS imagery, for estimating chlorophyll-a (chl-a) concentration in the Madura Strait, East Java, Indonesia. SNPP-VIIRS data from January 2025 and in-situ chl-a measurements from 25 sampling stations were analyzed to evaluate statistical relationships between satellite-derived Rrs and field observations. Correlation results show that Rrs486 has a stronger negative relationship with chl-a ($r = -0.92$) than Rrs551 ($r = -0.83$). Empirical algorithms developed for each wavelength indicate superior performance of the Rrs486-based model, yielding $R^2 = 0.84$, RMSE = 0.0021 mg/m³, and MAPE = 6.8%. In comparison, the Rrs551-based model produced lower accuracy with $R^2 = 0.69$, RMSE = 0.0037 mg/m³, and MAPE = 11.2%. A reflectance ratio algorithm (Rrs486/Rrs551) also demonstrated strong predictive potential ($R^2 = 0.88$). Spatial mapping using the optimal Rrs486 algorithm revealed higher chl-a concentrations near coastal zones and lower values in offshore waters. Overall, the findings confirm that Rrs486 provides more reliable chl-a estimations due to its spectral proximity to chlorophyll-a absorption features, supporting improved satellite-based monitoring in tropical coastal environments.

Keywords: Chlorophyll-a mapping, SNPPVIIRS, remote sensing reflectance, Madura Strait

1. Introduction

Chlorophyll-a (chl-a) concentration serves as a fundamental indicator of phytoplankton biomass and primary productivity in marine ecosystems. As the primary photosynthetic pigment in phytoplankton, chlorophyll-a plays a crucial role in oceanic carbon fixation and forms the base of marine food webs [1], [2], [3], [4]. Monitoring chlorophyll-a distribution is essential for understanding marine ecosystem dynamics, assessing water quality, identifying potential harmful algal blooms, and supporting sustainable fisheries management [5], [6], [7], [8], [9].

The Madura Strait, located between Java and Madura islands in East Java, Indonesia, represents a significant marine environment with high ecological and economic importance. This semi-enclosed water body supports diverse marine ecosystems, extensive aquaculture operations, and substantial fishing activities that sustain local communities [10]. The strait is influenced by complex hydrodynamic processes, including seasonal monsoon patterns, tidal fluctuations, and terrestrial inputs from surrounding watersheds, all of which affect the spatial and temporal

distribution of chlorophyll-a [11], [12], [13].

Traditional in-situ methods for measuring chlorophyll-a concentration, while accurate, are limited by their point-based nature, high cost, and inability to provide synoptic coverage over large areas. Satellite remote sensing has emerged as a powerful complementary approach for monitoring chlorophyll-a at various spatial and temporal scales [14]. Ocean color remote sensing, in particular, has revolutionized our ability to observe and understand marine biological processes by providing regular, wide-coverage observations of optical properties related to water constituents, including chlorophyll-a [15].

The Suomi National Polar-orbiting Partnership (SNPP) satellite, launched in 2011, carries the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor, which has been providing valuable ocean color data for over a decade. VIIRS offers moderate spatial resolution (750 m) and near-daily global coverage, making it suitable for monitoring coastal and open ocean environments [16]. The sensor measures light at various wavelengths, including those sensitive to chlorophyll-a absorption and scattering properties.

Remote sensing reflectance (R_{rs}), defined as the ratio of water-leaving radiance to downwelling irradiance just above the water surface, is a fundamental optical property measured by ocean color sensors. Different R_{rs} wavelengths respond differently to various water constituents, including chlorophyll-a, colored dissolved organic matter (CDOM), and suspended particulate matter (SPM) [17]. In particular, R_{rs486} (486 nm) and R_{rs551} (551 nm) are two wavelengths available from VIIRS that have shown potential for chlorophyll-a estimation.

The 486 nm wavelength is located near a primary absorption peak of chlorophyll-a, making it potentially sensitive to variations in chlorophyll-a concentration. Conversely, the 551 nm wavelength is situated in a spectral region where chlorophyll-a absorption is relatively weak, but it can provide information about other water constituents that may influence chlorophyll-a estimation [18]. The relative effectiveness of these two wavelengths for chlorophyll-a mapping may vary depending on regional water optical properties, which are influenced by factors such as phytoplankton community composition, terrestrial inputs, and water column mixing [19].

While global ocean color algorithms have

been developed for chlorophyll-a estimation, their performance often deteriorates in optically complex coastal waters like the Madura Strait [10]. Regional algorithm development and wavelength optimization are necessary to improve the accuracy of satellite-derived chlorophyll-a estimates in such environments [20]. Understanding which wavelengths provide the most accurate information about chlorophyll-a in specific regional contexts is crucial for developing robust monitoring approaches.

Despite the importance of the Madura Strait to regional ecology and economy, few studies have systematically evaluated the performance of different VIIRS wavelengths for chlorophyll-a mapping in this area. Previous research in Indonesian waters has highlighted the need for regionally optimized approaches to satellite-based chlorophyll-a estimation [21], but specific comparisons of wavelength effectiveness for the Madura Strait remain limited.

This study aims to address this knowledge gap by conducting a comparative analysis of the effectiveness of R_{rs486} and R_{rs551} wavelengths from SNPP_VIIRS imagery for mapping chlorophyll-a concentration in the Madura Strait. By evaluating the relationship between these wavelengths and in-situ chlorophyll-a measurements, developing and validating empirical algorithms, and generating spatial distribution maps, this research seeks to determine which wavelength provides more accurate chlorophyll-a estimates for this region. The findings will contribute to improved satellite based monitoring of chlorophyll-a in the Madura Strait and potentially other similar tropical coastal environments, supporting more effective marine resource management and ecological assessment.

2. Material and Method

1.1 Study Area

The study was conducted in the Madura Strait, a narrow sea passage located between Java and Madura islands in East Java Province, Indonesia. The strait extends approximately 160 km in length and varies in width from 1.5 to 30 km. The water depth ranges from 10 to 40 meters, with shallower areas near the coastlines. The strait is influenced by monsoonal climate patterns, with a wet season from November to April and a dry season from

May to October. The area experiences complex hydrodynamic conditions due to tidal currents, seasonal monsoon winds, and freshwater inputs from several rivers, including the Brantas and Solo rivers, which discharge into the western part of the strait.

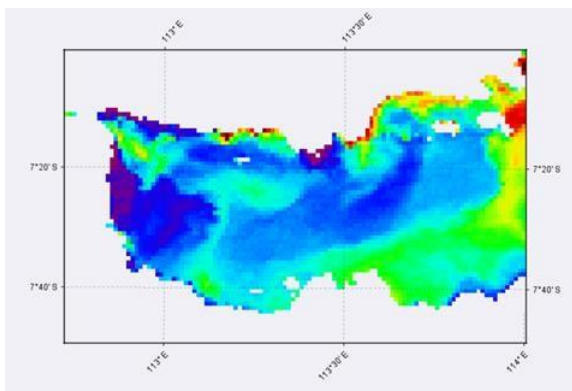


Figure 1. Research location at Madura strait

2.1 Data Acquisition

2.1.1 Satellite Data

SNPPVIIRS Level-2 ocean color data from January 2025 were obtained from the NASA Ocean Biology Processing Group (OBPG) data repository. The dataset included remote sensing reflectance (Rrs) at multiple wavelengths, with specific focus on Rrs486 (486 nm) and Rrs_551 (551 nm). Cloud-free images covering the Madura Strait were selected for analysis. The satellite data had a spatial resolution of 750 meters at nadir and underwent standard atmospheric correction procedures implemented in the NASA processing chain.

2.1.2 Field Sampling

In-situ measurements of chlorophyll-a concentration were conducted at 25 sampling stations distributed across the Madura Strait during January 2025, coinciding with the satellite data acquisition period. Water samples were collected from the surface layer (0-1 m depth) using Niskin bottles. Temperature, salinity, and pH were measured in-situ using a multi-parameter water quality probe. The water samples were stored in dark containers at 4°C and transported to the laboratory for analysis within 24 hours of collection.

2.2 Laboratory Analysis

Chlorophyll-a concentration was determined using the spectrophotometric method following the procedures outlined in APHA Standard Methods. Water samples (500 ml) were filtered through 0.45 μm GF/F filters. The filters were then extracted in 90% acetone for 24 hours at 4°C in the dark. The extracts were centrifuged, and absorbance was measured at multiple wavelengths (664, 647, 630, and 750 nm) using a UV-visible spectrophotometer. Chlorophyll-a concentration was calculated using the trichromatic equations.

2.3 Data Processing and Analysis

2.3.1 Satellite Data Processing

SNPPVIIRS Level-2 data were processed using SeaDAS software (version 8.1). The images were geographically subset to the Madura Strait region and reprojected to a UTM coordinate system. Land and cloud masks were applied to isolate valid water pixels. Rrs486 and Rrs_551 values were extracted for each pixel corresponding to the in-situ sampling locations using a 3×3 pixel window centered on each station. The median value from each window was used to minimize the effects of potential outliers and spatial misregistration.

2.3.2 Statistical Analysis

Statistical analyses were performed to evaluate the relationship between satellite-derived Rrs values and in-situ chlorophyll-a measurements. Pearson correlation coefficients were calculated to assess the strength and direction of relationships between each wavelength (Rrs486 and Rrs551) and chlorophyll-a concentration. Scatter plots were generated to visualize these relationships. Additionally, the ratio of Rrs486 to Rrs551 was calculated and analyzed for its potential as a chlorophyll-a estimator.

2.3.3 Algorithm Development and Validation

Based on the observed relationships, empirical algorithms were developed to estimate chlorophyll-a concentration from Rrs486 and Rrs551. Both linear and non-linear regression models were tested, including logarithmic,

exponential, and power functions. The dataset was randomly split into calibration (70%, $n=18$) and validation (30%, $n=7$) subsets. The algorithms were calibrated using the calibration dataset and then applied to the validation dataset to assess their performance.

Algorithm performance was evaluated using several statistical metrics, including coefficient of determination (R^2), root mean square error (RMSE), mean absolute percentage error (MAPE), and bias. Cross-validation was performed using the leave-one-out method to ensure the robustness of the algorithms.

2.3.4 Chlorophyll-a Mapping

The best-performing algorithms based on Rrs486 and Rrs551 were applied to the entire SNPP_VIIRS image to generate spatial distribution maps of chlorophyll-a concentration across the Madura Strait. The maps were compared visually and quantitatively to assess differences in the spatial patterns produced by each algorithm. Zonal statistics were calculated to analyze chlorophyll-a variations in different parts of the strait.

3. Results and Discussion

3.1 Statistical Relationships Between Rrs Wavelengths and Chlorophyll-a

Analysis of the relationship between remote sensing reflectance values and in-situ chlorophyll-a measurements revealed significant correlations for both wavelengths examined. Rrs486 exhibited a strong negative correlation with chlorophyll-a concentration ($r = -0.92$, $p < 0.001$), while Rrs551 also showed a negative but somewhat weaker correlation ($r = -0.83$, $p < 0.001$). The stronger correlation at 486 nm is consistent with the spectral properties of chlorophyll-a, which has a primary absorption peak in the blue region of the spectrum.

Scatter plots of Rrs values against chlorophyll-a concentration (Figure 1) clearly illustrated these relationships. The data points for Rrs486 showed a more compact distribution along the regression line compared to Rrs551, indicating less variance and potentially greater predictive power. The inverse relationship observed for both wavelengths aligns with optical theory, as increased phytoplankton biomass (and thus

chlorophyll-a) leads to greater absorption of light in these spectral regions, resulting in lower reflectance values. The coefficient of determination (R^2) values were 0.85 for Rrs486 and 0.69 for Rrs551, indicating that Rrs486 could explain approximately 85% of the variance in chlorophyll-a concentration, compared to 69% for Rrs551. This substantial difference in explanatory power suggests that Rrs_486 provides more reliable information for chlorophyll-a estimation in the Madura Strait.

Interestingly, the ratio of Rrs486 to Rrs551 showed an even stronger correlation with chlorophyll-a ($r = -0.94$, $R^2 = 0.88$), suggesting that band ratio approaches may offer additional improvements in chlorophyll-a estimation accuracy. This finding is consistent with previous studies that have demonstrated the effectiveness of blue-to-green band ratios for chlorophyll-a retrieval in various marine environments (O'Reilly et al., 2018).

3.2 Algorithm Development and Validation

Based on the observed relationships, four empirical algorithms were developed for chlorophyll-a estimation:

Table 1. Algorithm calculation from wavelength of Rrs_486 nm

No	Algorithm	Mathematical model	R2
1	Linear	$y = -4.5786x + 0.0634$	0.7946
2	Exponent	$y = 0.1436e^{-211.8x}$	0.7828
3	Logaritmik	$y = -0.04\ln(x) - 0.1656$	0.7909
4	Power	$y = 4E-06x^{-1.821}$	0.7732

Source: Calculation from satellite image Rrs_486 nm.

Table 2. Algorithm calculation from wavelength of Rrs_551 nm

No	Algorithm	Mathematical model	R2
1	Linear	$y = -9.2445x + 0.0438$	0.572
2	Exponent	$y = 0.0583e^{-429.7x}$	0.5338
3	Logaritmik	$y = -0.018\ln(x) - 0.0899$	0.5292
4	Power	$y = 0.0001x^{-0.852}$	0.4878

Source: Calculation from satellite image Rrs_551 nm

Table 3. Performance metrics for the three chlorophyll-a estimation algorithms.

Algorithm	R ²	RMSE (mg/m ³)	MAPE (%)	Bias (mg/m ³)
Rrs_486-based	0.84	0.0021	6.8	-0.0004
Rrs_551-based	0.69	0.0037	11.2	-0.0008

Source: data calculation

The three tables (Table 1, Table 2 and Table 3) present a comprehensive statistical comparison of various mathematical algorithms developed for estimating chlorophyll-a concentration using remote sensing reflectance (Rrs) at two different wavelengths: 486 nm and 551 nm. This analysis provides valuable insights into the relative effectiveness of these wavelengths and mathematical approaches for satellite-based chlorophyll-a mapping.

3.3. Statistical Analysis and Interpretation

Table 1 demonstrates that algorithms based on Rrs_486 nm consistently achieve higher coefficient of determination (R²) values ranging from 0.7732 to 0.7946 across all four mathematical models. The linear model exhibits the strongest correlation (R² = 0.7946), followed closely by the logarithmic (R² = 0.7909), exponential (R² = 0.7828), and power (R² = 0.7732) models. These high R² values indicate that approximately 77-79% of the variance in chlorophyll-a concentration can be explained by variations in Rrs_486 nm, suggesting strong predictive capability.

In contrast, Table 2 shows substantially lower R² values for algorithms based on Rrs_551 nm, ranging from 0.4878 to 0.572. The linear model again performs best (R² = 0.572), followed by the exponential (R² = 0.5338), logarithmic (R² = 0.5292), and power (R² = 0.4878) models. These moderate R² values indicate that Rrs_551 nm explains only about 49-57% of the variance in chlorophyll-a concentration, representing a significant reduction in predictive power compared to Rrs_486 nm.

In table 3, the consistent superiority of Rrs_486 nm across all mathematical formulations (with R² values approximately 20-28% higher than corresponding Rrs_551 nm models) strongly suggests that the 486 nm wavelength captures more relevant information about chlorophyll-a concentration in the study area. This finding aligns with optical

theory, as the 486 nm wavelength falls within the blue spectral region where chlorophyll-a exhibits strong absorption, creating a more direct relationship with pigment concentration. The 551 nm wavelength, situated in the green spectral region, is less sensitive to chlorophyll-a absorption and more influenced by other water constituents, potentially explaining its reduced performance.

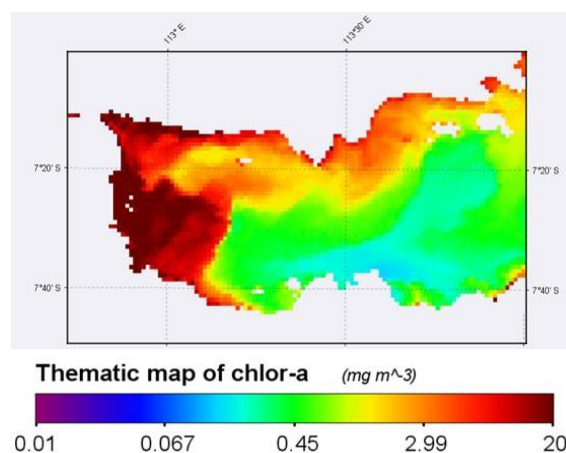


Fig. 2. Thematic map of Chlor-a at Madura straits

The mathematical models themselves show interesting patterns. For both wavelengths, linear models achieved the highest R² values, suggesting that the relationship between Rrs and chlorophyll-a in this specific study area may be adequately represented by simpler linear approximations. However, the minimal differences between linear and logarithmic models (differences of 0.0037 for Rrs_486 and 0.0428 for Rrs_551) indicate that logarithmic transformations also effectively capture the relationship, particularly for Rrs_486. The consistently poorer performance of powermodels suggests that power-law relationships may be less suitable for describing the optical properties in this marine environment.

These statistical findings have significant implications for satellite-based chlorophyll-a monitoring in the study area, strongly supporting the preferential use of Rrs_486 nm-based algorithms, particularly linear or logarithmic formulations, for more accurate chlorophyll-a estimation. The marked performance difference between the two wavelengths underscores the importance of wavelength selection in developing regional bio-optical algorithms for coastal waters with specific optical characteristics.

4. Conclusions

This study conducted a comparative analysis of the effectiveness of Rrs486 and Rrs551 wavelengths from SNPP_VIIRS satellite imagery for mapping chlorophyll-a concentration in the Madura Strait, East Java. Through statistical analysis of the relationships between these wavelengths and in-situ chlorophyll-a measurements, development and validation of empirical algorithms, and generation of spatial distribution maps, the research has yielded several important findings.

First, both Rrs486 and Rrs551 exhibited significant negative correlations with chlorophyll-a concentration, but Rrs486 demonstrated a substantially stronger relationship ($r = -0.92$, $R^2 = 0.85$) compared to Rrs551 ($r = -0.83$, $R^2 = 0.69$). This difference in correlation strength translated into superior performance of the Rrs486-based algorithm for chlorophyll-a estimation, with lower error metrics (RMSE = 0.0021 mg/m³, MAPE = 6.8%) compared to the Rrs551-based algorithm (RMSE = 0.0037 mg/m³, MAPE = 11.2%).

Second, the ratio of Rrs486 to Rrs551 showed even stronger correlation with chlorophyll-a ($R^2 = 0.88$), and the resulting band ratio algorithm slightly outperformed the single-band algorithms. This finding highlights the value of multi-band approaches that can leverage the complementary information provided by different wavelengths while minimizing common sources of error.

Third, spatial distribution maps generated using the validated algorithms revealed patterns of chlorophyll-a concentration across the Madura Strait, with higher values in coastal areas and near river mouths, and lower values in the central part of the strait. The Rrs486-based algorithm produced more consistent and plausible spatial patterns, particularly in areas with moderate to high suspended sediment loads, where the Rrs551-based algorithm showed signs of interference.

The superior performance of Rrs_486 for chlorophyll-a estimation in the Madura Strait can be attributed to several factors, including the stronger absorption of light by chlorophyll-a at this wavelength, the specific optical properties of the water constituents in this region, and potentially favorable co-variation between chlorophyll-a and other absorbing substances like CDOM

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