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ANALYSIS OF CHLOROPHYLL-A DISTRIBUTION CONCENTRATION TO DETERMINE WATER PRODUCTIVITY IN BARRANG CADDI ISLAND

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Abstract

This study aimed to analyze the distribution of chlorophyll-*a* concentration and determine the water productivity status in Barrang Caddi Island, Makassar, Indonesia. Chlorophyll-*a* is widely recognized as an important indicator of phytoplankton abundance and primary productivity in marine ecosystems. The study was conducted in May 2025 using two approaches, namely direct measurements through spectrophotometric analysis and remote sensing analysis based on Aqua MODIS satellite imagery processed using SeaDAS software. Water samples were collected from three sampling stations, while satellite observations were performed weekly throughout the study period. The accuracy of satellite-derived chlorophyll-*a* data was evaluated using the Root Mean Square Error (RMSE) method. Spectrophotometric analysis revealed that chlorophyll-*a* was detected only at Station 2, with a concentration of 0.068 mg m^{-3}, whereas concentrations at Stations 1 and 3 were below the detection limit. In contrast, remote sensing analysis showed higher chlorophyll-*a* concentrations ranging from 0.740 to 1.244 mg m^{-3} during the observation period. These values indicate that the waters surrounding Barrang Caddi Island were generally characterized by moderate productivity and classified as mesotrophic. The RMSE value between laboratory measurements and satellite-derived estimates was 1.176 mg m^{-3}, indicating a considerable discrepancy between the two methods. Despite this difference, remote sensing proved effective for describing the spatial and temporal distribution of chlorophyll-*a* over a wide area. The findings suggest that Barrang Caddi Island waters possess moderate biological productivity and have the potential to support sustainable fisheries and other marine resource management activities.

Keywords: *Chlorophyll; Mesotrophic; Phytoplankton; Productivity; Remote sensing*

INTRODUCTION

Barrang Caddi Island is one of the inhabited small islands located within the Spermonde Archipelago in the Makassar Strait, South Sulawesi, Indonesia. Administratively, the island belongs to Barrang Caddi Village, Sangkarrang Islands District, Makassar City. Similar to many small islands in eastern Indonesia, Barrang Caddi possesses highly valuable marine ecosystems that support fisheries, tourism, and coastal livelihoods. The surrounding waters are characterized by diverse biological resources and provide essential ecological services for local communities. However, increasing anthropogenic pressures and environmental changes have raised concerns regarding the sustainability of marine resources, making continuous monitoring of water productivity increasingly important (Abdul Rauf et al., 2024; Asniwati et al., 2022). According to the Intergovernmental Oceanographic Commission (IOC, 2023), understanding primary productivity is fundamental for evaluating ecosystem health and supporting sustainable marine resource management.

Water productivity reflects the capacity of aquatic ecosystems to generate organic matter through photosynthesis and other biological processes. Primary productivity is largely controlled by solar radiation, nutrient availability, temperature, hydrodynamic conditions, and the abundance of photosynthetic organisms such as phytoplankton and microalgae (Behrenfeld & Boss, 2018). As the primary producers in marine food webs, phytoplankton form the basis of energy transfer from lower trophic levels to higher organisms, including commercially important fish species. Consequently, the spatial and temporal distribution of phytoplankton biomass serves as an important indicator of the fertility and biological productivity of marine waters (Paerl et al., 2020). Variations in productivity are closely associated with ecosystem functioning and influence fisheries potential, biodiversity conservation, and carbon cycling (Falkowski et al., 2021).

Among various biological indicators, chlorophyll-a has been widely recognized as one of the most reliable proxies for estimating phytoplankton biomass and assessing primary productivity. Chlorophyll-a is a green pigment responsible for absorbing solar energy during photosynthesis and is present in all photosynthetic phytoplankton species (Werdell et al., 2019). Because chlorophyll-a concentration is directly related to phytoplankton abundance, it has become a standard parameter for evaluating trophic conditions and biological productivity in marine ecosystems (Maslukah et al., 2022). According to Wang et al. (2021), chlorophyll-a concentration provides valuable information regarding nutrient dynamics and ecosystem responses to environmental changes. Similarly, Wulandari et al. (2024) emphasized that chlorophyll-a serves as an effective indicator for understanding marine ecosystem stability and supporting fisheries management.

The significance of chlorophyll-a extends beyond its role as an indicator of phytoplankton abundance. Variations in chlorophyll-a concentration reflect nutrient availability, water circulation, and ecological interactions within aquatic ecosystems. High concentrations of chlorophyll-a are generally associated with eutrophic conditions and elevated primary productivity, whereas low concentrations indicate oligotrophic environments characterized by limited nutrient availability (Sunaryani, 2023). According to Kholik (2024), chlorophyll-a plays an important role in determining water fertility because it strongly correlates with nutrient concentrations and environmental quality parameters. Consequently, information on chlorophyll-a distribution can provide insights into suitable areas for fisheries, mariculture development, and other marine-related activities.

Water fertility status is commonly classified into oligotrophic, mesotrophic, and eutrophic categories. Oligotrophic waters are characterized by low nutrient concentrations and limited productivity, while mesotrophic waters represent intermediate conditions with moderate biological productivity. In contrast, eutrophic waters contain high nutrient concentrations and are generally associated with increased phytoplankton biomass, lower transparency, and reduced dissolved oxygen concentrations (Sunaryani, 2023). Excessive eutrophication may trigger harmful algal blooms and disrupt ecosystem balance, whereas oligotrophic conditions may limit biological production. Therefore, understanding trophic status through chlorophyll-a analysis is essential for maintaining ecological sustainability and ensuring rational utilization of marine resources (Paerl et al., 2020).

Conventional methods for measuring chlorophyll-a typically involve direct sampling and laboratory analysis, which provide accurate results but are limited in spatial coverage and require considerable time and financial resources. As marine ecosystems are dynamic and heterogeneous, field observations alone may not adequately represent large-scale patterns of chlorophyll-a distribution (Mouw et al., 2019). Consequently, remote sensing technology has emerged as an efficient alternative for monitoring oceanographic parameters over extensive areas and at multiple temporal scales. Satellite observations enable researchers to obtain continuous and synoptic information on chlorophyll-a concentrations, thereby facilitating ecosystem assessment and environmental monitoring (Werdell et al., 2019).

Recent advances in remote sensing have significantly improved the capability to estimate chlorophyll-a concentrations in coastal and oceanic waters. Satellite sensors such as MODIS, Sentinel-3 OLCI, and Landsat-8 OLI provide high-resolution imagery that can be used to derive chlorophyll-a concentrations through various empirical and semi-analytical algorithms (Mouw et al., 2019). According to Ningrum et al. (2024), remote sensing techniques offer substantial advantages compared with conventional approaches because they allow rapid assessment of water quality and productivity with greater spatial coverage. Moreover, the availability of long-term satellite datasets enables the analysis of temporal changes and seasonal variability in marine productivity. Such information is particularly valuable for coastal management and fisheries planning.

In the context of the Spermonde Archipelago, several studies have reported considerable spatial variability in chlorophyll-a concentrations due to differences in hydrodynamic conditions, nutrient inputs, and anthropogenic influences. Coastal waters surrounding inhabited islands often exhibit higher chlorophyll-a concentrations than offshore areas because of nutrient enrichment derived from domestic activities and terrestrial runoff (Maslukah et al., 2022). Furthermore, climatic factors, monsoonal circulation, and upwelling processes contribute to fluctuations in phytoplankton abundance and water fertility throughout the year (Wang et al., 2021). Despite the ecological and economic importance of Barrang Caddi Island, information regarding chlorophyll-a distribution and water productivity in this area remains limited. Most previous studies have focused on coral reef ecosystems and coastal environmental quality, whereas comprehensive investigations concerning chlorophyll-a dynamics are still scarce.

Understanding the spatial distribution of chlorophyll-a around Barrang Caddi Island is essential for supporting sustainable fisheries and marine resource utilization. Chlorophyll-a distribution patterns can serve as indicators of potential fishing grounds because pelagic fish abundance is strongly influenced by phytoplankton productivity and food availability (Falkowski et al., 2021). Moreover, information regarding productive waters may provide guidance for mariculture development, marine ecotourism, and ecosystem conservation strategies. In addition, monitoring chlorophyll-a concentrations can contribute to early detection of environmental degradation and facilitate adaptive management in response to climate variability and anthropogenic pressures (Behrenfeld & Boss, 2018).

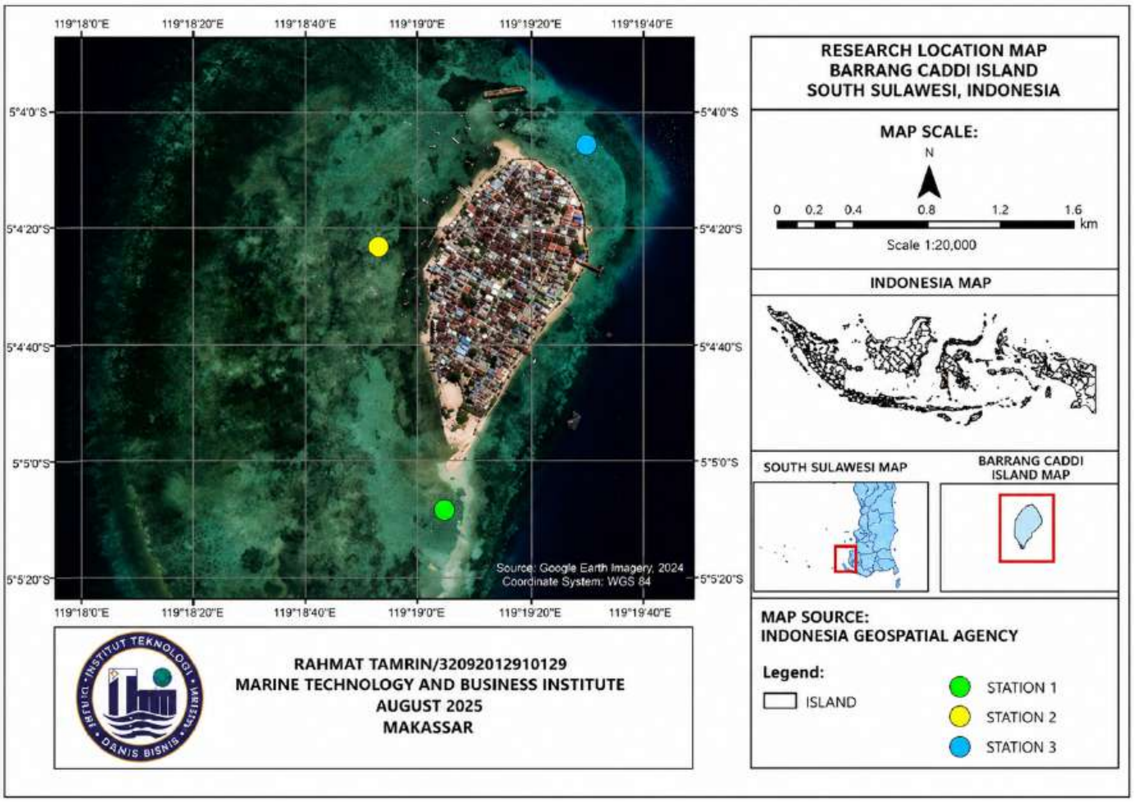
Given the importance of chlorophyll-a as a biological indicator and the advantages offered by remote sensing technology, a comprehensive assessment of chlorophyll-a distribution in the waters surrounding Barrang Caddi Island is necessary. Such studies are expected to provide scientific information regarding the spatial characteristics of water productivity and support sustainable management of coastal ecosystems. Therefore, the present study aims to analyze the distribution of chlorophyll-a concentrations in the waters of Barrang Caddi Island using remote sensing techniques in order to determine the level of water productivity and provide recommendations for the sustainable utilization of marine resources. The findings are expected to contribute not only to understanding ecosystem dynamics in the Spermonde Archipelago but also to supporting fisheries management, marine spatial planning, and environmental conservation in coastal areas with similar characteristics.

METHODS

This study was conducted in May 2025 in the waters surrounding Barrang Caddi Island, Sangkarrang Islands District, Makassar City, South Sulawesi, Indonesia. Field sampling was carried out on 15 May 2025, while satellite image processing was performed on a weekly basis throughout the study period. Barrang Caddi Island is located within the Spermonde Archipelago and represents an important coastal ecosystem characterized by productive marine waters. The study area is presented in Figure 1. The research employed a quantitative approach integrating in situ observations with remote sensing techniques to determine chlorophyll-a distribution and assess water productivity. Chlorophyll-a concentration was used as an indicator of phytoplankton abundance and primary productivity because phytoplankton constitute the primary producers within marine food webs (Wang et al., 2021; Maslukah et al., 2022). Satellite data were obtained from Aqua MODIS (Moderate Resolution Imaging Spectroradiometer), whose spectral bands in the blue, green, and red regions are highly sensitive to chlorophyll-a concentrations in surface waters. The application of MODIS imagery allows broad and efficient monitoring of marine productivity compared with conventional sampling methods (Mouw et al., 2019; Ningrum et al., 2024).

Figure 1.

Study area map of Barrang Caddi Island here



The distribution of chlorophyll-a concentration derived from Aqua MODIS imagery was analyzed spatially to describe the productivity characteristics of the study area. Subsequently, the accuracy of satellite-derived chlorophyll-a data was evaluated by comparing image extraction results with laboratory measurements using the Root Mean Square Error (RMSE) approach. RMSE represents the magnitude of deviation between satellite-derived values and observed values, where smaller RMSE values indicate better agreement and higher accuracy (Werdell et al., 2019; Kholik, 2024). The RMSE was calculated using the following equation:

$$RMSE = \sqrt{\frac{\Sigma(z_i - z_j)}{n}}$$

where Z_i = Image analysis data, Z_j = Laboratory analysis data, n= Amount of data. The resulting chlorophyll-a distribution maps were interpreted descriptively to determine the productivity status of the waters surrounding Barrang Caddi Island. The findings were further classified according to trophic conditions, namely oligotrophic, mesotrophic, and eutrophic waters, which reflect differences in nutrient availability and biological productivity (Sunaryani, 2023; Wulandari et al., 2024). Such information is essential for supporting sustainable fisheries management, identifying potential fishing grounds, and optimizing marine resource utilization in the Spermonde Archipelago.

RESULTS AND DISCUSSION

Laboratory-Based Chlorophyll-a Measurements

Laboratory analysis using the spectrophotometric method was performed to determine chlorophyll-a concentrations from seawater samples collected at three observation stations around Barrang Caddi Island. Chlorophyll-a concentration is widely recognized as an indicator of phytoplankton abundance and primary productivity in marine ecosystems (Maslukah et al., 2022; Wulandari et al., 2024). The results obtained from laboratory measurements are presented in Table 1.

Table 1.

Chlorophyll-a concentration determined using spectrophotometric analysis here

Station	Chlorophyll-a Concentration (mg m^{-3})	Detection Status	Analytical Method
ST1	<0.001	Not Detected (ND)	Spectrophotometry
ST2	0.068	Detected	Spectrophotometry
ST3	<0.001	Not Detected (ND)	Spectrophotometry

Source: Research results

The spectrophotometric analysis revealed that chlorophyll-a was detected only at Station 2, with a concentration of 0.068 mg m^{-3}, whereas chlorophyll-a concentrations at Stations 1 and 3 were below the detection limit (<0.001 mg m^{-3}). These findings indicate a spatial variation in phytoplankton abundance among sampling locations. The low chlorophyll-a concentration observed at Station 2 suggests limited phytoplankton biomass, while the absence of detectable chlorophyll-a at Stations 1 and 3 may reflect low nutrient availability or strong hydrodynamic processes that inhibit phytoplankton accumulation.

According to OECD trophic classifications, chlorophyll-a concentrations below 0.1 mg m^{-3} are generally categorized as oligotrophic conditions characterized by low nutrient concentrations and low biological productivity. Similar observations were reported by Akbar (2023), who demonstrated that oligotrophic waters are commonly associated with low phytoplankton biomass and reduced primary productivity. Environmental factors such as nutrient availability, water circulation, sunlight intensity, and tidal fluctuations are known to influence chlorophyll-a distribution in coastal ecosystems (Behrenfeld & Boss, 2018; Paerl et al., 2020). Therefore, the differences observed among stations likely reflect local environmental heterogeneity around Barrang Caddi Island.

Chlorophyll-a Distribution Derived from Aqua MODIS Imagery

Satellite-based analysis was conducted using Aqua MODIS imagery processed with SeaDAS software to evaluate the spatial and temporal distribution of chlorophyll-a during May 2025. Remote sensing techniques provide continuous and large-scale observations of

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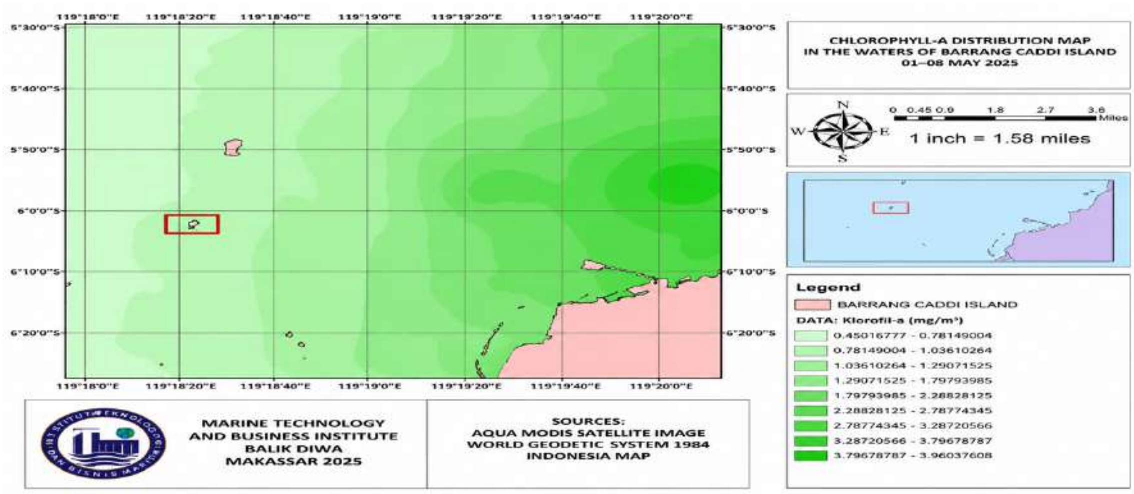
marine productivity and have become valuable tools for coastal monitoring (Wang et al., 2021; Ningrum et al., 2024).

Figure 2.

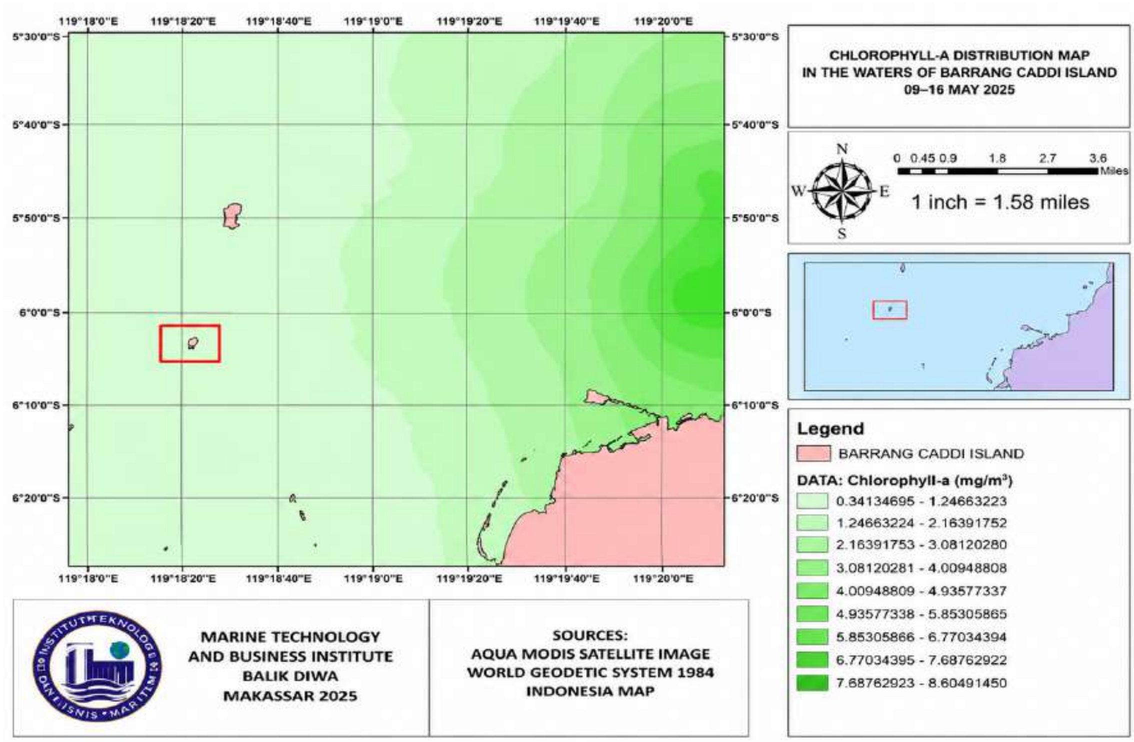
Chlorophyll-a distribution map during



During the first observation period (1–8 May 2025), chlorophyll-a concentrations ranged from approximately 0.78 to 1.43 mg m^{-3}. These values indicate moderate productivity levels, corresponding to mesotrophic waters. Such concentrations suggest that phytoplankton populations were sufficiently abundant to support marine food webs without indicating excessive nutrient enrichment.

Figure 3.

Chlorophyll-a distribution map during



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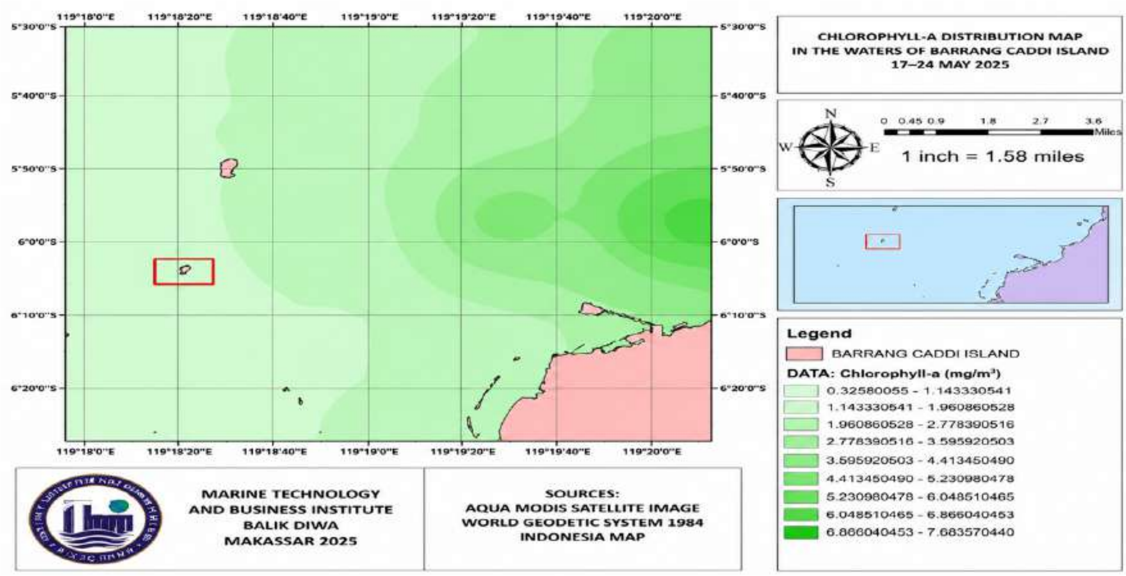
The second observation period (9–16 May 2025) showed chlorophyll-a concentrations varying between 0.30 and 1.24 mg m^{-3}. Although lower values were observed compared with the previous week, the waters remained within the mesotrophic category. Variations in chlorophyll-a concentration may be attributed to changes in oceanographic conditions, including current patterns, rainfall, and solar radiation intensity.

Figure 4.

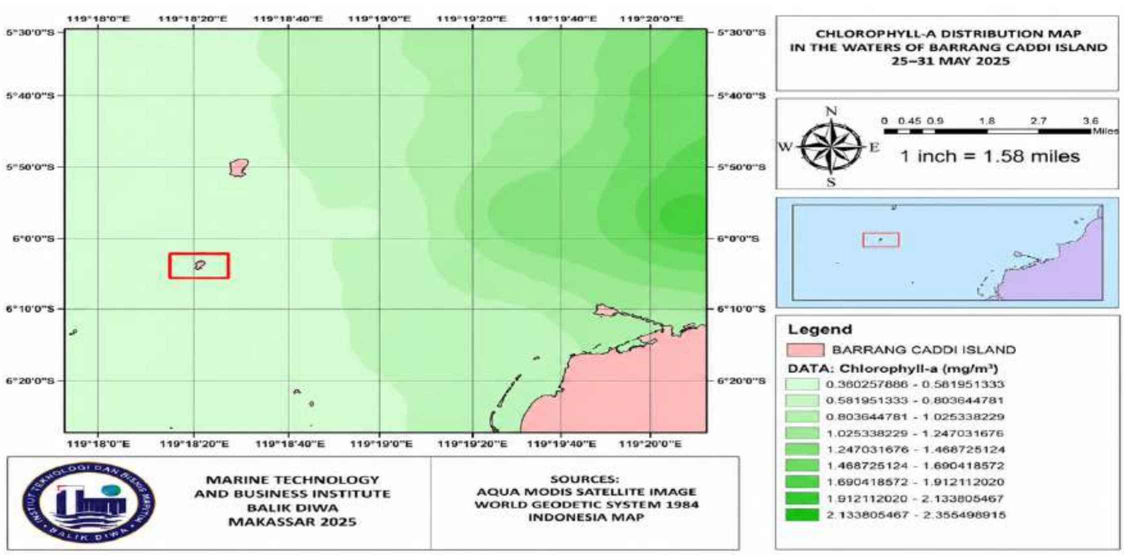
Chlorophyll-a distribution map during



During 17–24 May 2025, chlorophyll-a concentrations ranged from 0.33 to 1.14 mg m^{-3}. Similar to previous observations, the distribution pattern indicated moderate biological productivity. Stable chlorophyll-a levels throughout the month suggest relatively balanced nutrient dynamics and environmental conditions.

Figure 5.

Chlorophyll-a distribution map during



The final observation period (25–31 May 2025) exhibited chlorophyll-a concentrations between 0.34 and 0.74 mg m^{-3}. Although lower than earlier weeks, these concentrations still corresponded to mesotrophic conditions. The decrease in chlorophyll-a concentration during the final week may be associated with reduced nutrient availability or changes in water circulation patterns.

Overall, chlorophyll-a concentrations obtained from Aqua MODIS imagery ranged from 0.30 to 1.24 mg m^{-3}. According to Puspitaloka et al., waters with chlorophyll-a concentrations between 0.5 and 2.0 mg m^{-3} are categorized as mesotrophic and exhibit moderate productivity. Similar concentration ranges have been reported for coastal waters influenced by moderate nutrient inputs and stable physical conditions (Werdell et al., 2019; Mouw et al., 2019).

Implications for Water Productivity

The observed chlorophyll-a concentrations indicate that the waters surrounding Barrang Caddi Island exhibit moderate productivity. Mesotrophic conditions generally support diverse marine communities and provide favorable conditions for fishery resources. Phytoplankton serves as the base of marine food webs and plays a crucial role in sustaining pelagic fish populations and higher trophic levels (Falkowski et al., 2021).

The relatively homogeneous distribution of chlorophyll-a around the island suggests effective nutrient transport driven by tidal currents and local circulation processes. Such conditions are beneficial for maintaining ecosystem stability and supporting sustainable fisheries. Moreover, chlorophyll-a distribution can serve as an early indicator of environmental changes and anthropogenic disturbances, including nutrient enrichment and coastal pollution (Paerl et al., 2020).

Comparison between Spectrophotometric and Remote Sensing Approaches

To evaluate differences between laboratory measurements and satellite-derived chlorophyll-a concentrations, both approaches were compared. Laboratory analysis indicated extremely low chlorophyll-a concentrations, whereas remote sensing data showed values ranging from 0.740 to 1.244 mg m^{-3}.

Table 2.

Chlorophyll-a concentrations obtained using spectrophotometric analysis

Sampling Station	Chlorophyll-a Concentration (mg m^{-3})	Remarks
ST1	0.000	Not detected
ST2	0.068	Detected
ST3	0.000	Not detected

Source: Research results

The spectrophotometric method detected chlorophyll-a only at Station 2, suggesting oligotrophic conditions during field sampling. Because laboratory measurements are based on discrete water samples collected at specific times and locations, they provide highly accurate point-based observations.

Table 3.
Chlorophyll-a concentrations derived from Aqua MODIS imagery

Observation Period	Chlorophyll-*a* Concentration (mg m⁻³)	Trophic Status
Week 1 (1–8 May 2025)	1.108	Eutrophic
Week 2 (9–16 May 2025)	1.244	Eutrophic
Week 3 (17–24 May 2025)	1.143	Eutrophic
Week 4 (25–31 May 2025)	0.740	Mesotrophic

Source: Research results

Remote sensing analysis showed chlorophyll-a concentrations of 1.108, 1.244, 1.143, and 0.740 mg m^{-3}. Three measurements exceeded 1.0 mg m^{-3}, indicating relatively high productivity, whereas one value represented moderate productivity. Temporal fluctuations in chlorophyll-a concentration may reflect variations in sea surface temperature, sunlight intensity, rainfall, tidal conditions, and phytoplankton dynamics.

To assess the agreement between both approaches, Root Mean Square Error (RMSE) analysis was performed. The RMSE value obtained was 1.176 mg m^{-3}. In general, lower RMSE values indicate higher agreement and better accuracy between satellite-derived and field-based measurements (Werdell et al., 2019). The relatively high RMSE observed in this study suggests considerable differences between laboratory observations and remote sensing estimates.

These discrepancies may arise from differences in spatial and temporal resolution, atmospheric interference affecting satellite imagery, and variability in phytoplankton distribution. Similar inconsistencies between field measurements and ocean-color remote sensing products have been reported in tropical coastal waters, where optical complexity and suspended materials influence chlorophyll-a retrieval accuracy (Mouw et al., 2019; Wang et al., 2021). Therefore, combining laboratory measurements and remote sensing approaches provides a more comprehensive understanding of water productivity and improves the reliability of marine ecosystem assessments.

CONCLUSION

The results of this study demonstrated that chlorophyll-*a* concentrations in the waters surrounding Barrang Caddi Island varied depending on the analytical method employed. Spectrophotometric measurements indicated very low chlorophyll-*a* concentrations, with only Station 2 recording a detectable value of 0.068 mg m^{-3}, while concentrations at Stations 1 and 3 were below the detection limit. Conversely, Aqua MODIS remote sensing analysis showed chlorophyll-*a* concentrations ranging from 0.740 to 1.244 mg m^{-3} throughout May 2025, suggesting moderate water productivity. Based on the chlorophyll-*a* concentration obtained from satellite imagery, the waters of Barrang Caddi Island can be classified as mesotrophic, indicating moderate fertility and sufficient phytoplankton abundance to support marine food webs and fisheries resources. The RMSE value of 1.176 mg m^{-3} revealed noticeable differences between laboratory measurements and satellite-derived estimates, suggesting that satellite data should be validated using in situ observations to improve accuracy. Overall, remote sensing provides an efficient tool for monitoring chlorophyll-*a* distribution and assessing the productivity status of coastal waters, thereby supporting sustainable marine resource management in Barrang Caddi Island and surrounding areas.

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