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Implementation of MODIS Satellite Image Processing Using SeaDAS Software to Analyze Chlorophyll-a Distribution in Aceh Seawaters Before and After the COVID-19 Pandemic

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ABSTRACT

Chlorophyll-a is an important oceanographic parameter that reflects the level of primary productivity in the waters and the abundance of phytoplankton as the primary producers in the marine food chain. This study aims to analyze a comparison of chlorophyll-a distribution based on Aqua MODIS and Terra MODIS data in the waters off Aceh during the periods before and after the COVID-19 pandemic.The data used were MODIS Level-3 chlorophyll-a data for the period July–December 2019, representing pre-pandemic conditions, and for the period January–June 2023, representing post-COVID-19 pandemic conditions. Data processing was performed using SeaDAS software version 7.3.2 through the stages of preprocessing, cropping, land masking, visualization, and descriptive statistical extraction, which included the minimum, maximum, and average chlorophyll-a concentrations. Further analysis was conducted using Microsoft Excel to generate graphs and comparison tables for the four data sets. The results of the study show that chlorophyll-a concentrations tend to be higher in coastal areas than in offshore waters, indicating a high supply of nutrients from land via river runoff and water mass mixing processes. The average Aqua MODIS chlorophyll-a concentration decreased from 0.3169 mg/m³ in 2019 to 0.2148 mg/m³ in 2023, while Terra MODIS showed a decrease from 0.3076 mg/m³ to 0.2411 mg/m³ over the same period. The decline in chlorophyll-a concentrations following the COVID-19 pandemic indicates changes in primary productivity in the waters, influenced by oceanographic dynamics such as sea surface temperature, current patterns, monsoon winds, and nutrient distribution. Although there were differences in concentration values between the two sensors due to variations in satellite overpass times and atmospheric conditions at the time of recording, both sensors produced relatively consistent spatial distribution patterns. The results of this study are expected to serve as a reference for the management of marine and fishery resources using remote sensing technology in the waters of Aceh.

I. Introduction

Indonesia is an archipelagic nation with vast maritime territories and significant fisheries potential. One region with significant fisheries potential is the waters off Aceh, which border directly on the Indian Ocean, the Strait of Malacca, and the Andaman Sea. This geographical location gives the waters of Aceh complex and dynamic oceanographic characteristics due to the influence of ocean currents, monsoon winds, and the interaction of water masses from surrounding waters. These oceanographic conditions affect the fertility of the waters, which plays a crucial role in supporting the productivity of fishery resources and marine ecosystems [1].

One of the parameters commonly used to describe the fertility of a body of water is chlorophyll-a concentration. Chlorophyll-a is the primary pigment found in phytoplankton and plays a role in photosynthesis. Chlorophyll-a concentration is often used as an indicator of primary productivity

because it reflects the abundance of phytoplankton in a body of water. High chlorophyll-a concentrations indicate high levels of biological productivity, which can support fish populations [2]. Direct observation of chlorophyll-a concentrations through field surveys is relatively costly, time-consuming, and limited in geographic scope. Therefore, remote sensing technology has become an effective method for monitoring oceanographic conditions both spatially and temporally. Satellite imagery data enables the observation of water conditions over a wide geographic area on a continuous basis, thereby providing information more efficiently than conventional measurement methods [3].

One of the satellite sensors widely used in oceanographic research is the Moderate Resolution Imaging Spectroradiometer (MODIS), which is mounted on the Terra and Aqua satellites. The MODIS sensor is capable of providing various oceanographic parameters such as sea surface temperature, chlorophyll-a concentration, and primary productivity of the waters. Terra MODIS records data during the morning pass, while Aqua MODIS records data during the afternoon pass. This difference in acquisition times has the potential to result in differences in the chlorophyll-a concentration values obtained, even though both satellites use the same sensor [4].

Future research is recommended to use a longer data period and to compare the same months or seasons across years in order to minimize the impact of seasonal variations on chlorophyll-a concentrations. In addition, the use of field (in-situ) data as validation data is also necessary to improve the accuracy of the observation results. Deforestation monitoring can be conducted using remote sensing technology via satellite imagery. Satellite imagery can provide information on land cover conditions and vegetation changes in a given area over a specific period of time. One type of data that can be used to monitor forest changes is satellite imagery [5]

In addition to being influenced by nutrient input from land, the distribution of chlorophyll-a is also influenced by oceanographic factors such as ocean currents, monsoon winds, sea surface temperature, and water mass mixing processes. The variability in chlorophyll-a concentrations in the western waters of Aceh is influenced by changes in the direction and intensity of monsoon winds, which cause water mass mixing and nutrient distribution in the surface layer of the ocean [4]. Oceanographic conditions, such as sea surface temperature and water mass dynamics, affect the distribution of chlorophyll-a in various Indonesian waters [6]. These conditions indicate that variations in chlorophyll-a concentration result from the interaction between biological and oceanographic factors occurring in a given body of water.

Several studies in Indonesian waters have shown that chlorophyll-a concentrations are generally higher in coastal areas than in the open ocean due to nutrient inputs from rivers and land-based activities. The variations in chlorophyll-a concentrations in coastal waters are influenced by local oceanographic conditions and the availability of nutrients that support phytoplankton growth [2]. Meanwhile, [3] explain that Aqua MODIS data can be used to analyze primary productivity in coastal waters because it has the capability to monitor chlorophyll-a dynamics on a regular basis.

The COVID-19 pandemic, which began in 2020, led to changes in various human activities, including in the transportation, fisheries, industrial, and tourism sectors. These changes in activity are believed to have influenced aquatic environmental conditions, potentially resulting in shifts in chlorophyll-a distribution before and after the pandemic. It is important to analyze conditions before and after the pandemic to determine whether there have been changes in aquatic productivity characteristics as reflected by chlorophyll-a concentrations.

Although numerous studies on chlorophyll-a distribution using MODIS data have been conducted, research specifically comparing chlorophyll-a distribution based on Aqua MODIS and Terra MODIS data during the periods before and after the COVID-19 pandemic in the waters off Aceh remains relatively limited. Most previous studies have focused on only one type of sensor or a specific observation period. Therefore, this study was conducted to analyze a comparison of chlorophyll-a distribution based on Aqua MODIS and Terra MODIS data in the waters off Aceh before and after the COVID-19 pandemic. The results of this study are expected to provide information on the characteristics of chlorophyll-a distribution and changes in marine productivity, as well as serve as a reference for the management of marine and fishery resources using remote sensing technology.

However, studies specifically comparing chlorophyll-a distribution using Aqua MODIS and Terra MODIS data before and after the COVID-19 pandemic in the waters off Aceh remain relatively limited. Therefore, this study was conducted to analyze the comparison of chlorophyll-a distribution in the waters off Aceh before and after the COVID-19 pandemic using Aqua MODIS and Terra MODIS data. The results of this study are expected to provide information on changes in marine productivity and the characteristics of chlorophyll-a distribution, as well as to support remote sensing-based management of marine and fishery resources.

II. Literature Review

A. Chlorophyll-a as an Indicator of Primary Productivity in Aquatic Ecosystems

Chlorophyll-a is a key oceanographic parameter widely used to characterize the level of primary productivity and fertility of a body of water, as this pigment is directly related to the abundance of phytoplankton, the primary producers in the marine food chain. Conventional monitoring of chlorophyll-a through field surveys has limitations in terms of cost, time, and geographic coverage; consequently, satellite remote sensing technology, specifically the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the Aqua and Terra satellites has become a widely used alternative for monitoring the spatial and temporal dynamics of chlorophyll-a [1].

Several studies have confirmed that chlorophyll-a concentration is a representative proxy for assessing the fertility and biological productivity of a water body. In a study of chlorophyll-a variability in the waters of West Kalimantan using five years of MODIS Aqua data (2016–2020), found that the highest chlorophyll-a concentrations were consistently found in coastal areas compared to the open ocean, with distinct monthly variations, the highest concentration occurring in August (28.93 mg/m³) [7]. A similar pattern was also reported by [1] in the waters off Aceh, indicating that chlorophyll-a distribution can be used to help identify potential fishing grounds for local fishermen. These findings are consistent with the results of the study under review, which also found higher chlorophyll-a concentrations in the coastal waters of Aceh compared to offshore waters due to nutrient input from land and water mass mixing.

B. The Use of Aqua MODIS and Terra MODIS Data in Chlorophyll-a Monitoring

The MODIS sensor, installed on two different satellite platforms Aqua MODIS (daytime orbit) and Terra MODIS (morning orbit) have been widely used for oceanographic studies due to its high temporal resolution and extensive spatial coverage. [8] used Aqua MODIS imagery to analyze the variability in chlorophyll-a distribution at coal loading and unloading sites in the waters off West Aceh and Nagan Raya and to relate it to ocean current patterns, finding that current dynamics also influence chlorophyll-a distribution in the region. Meanwhile, [9] conducted a spatial and temporal analysis of sea surface temperature and chlorophyll-a over two decades in Indonesian waters using satellite data, confirming that changes in oceanographic conditions such as sea surface temperature are closely linked to fluctuations in chlorophyll-a concentrations on a long-term timescale. Direct comparisons between Aqua MODIS and Terra MODIS are still relatively rare, so studies that compare these two sensors simultaneously make an important contribution to understanding the consistency and differences in chlorophyll-a estimation results due to differences in image acquisition timing.

Utilization Landsat 8 OLI imagery to conduct a visually-based land cover classification in Tapaktuan Subdistrict, South Aceh, as a follow-up to a previous study on nutmeg plantation mapping using the same satellite imagery [10]. These studies demonstrate that the satellite image processing methodology ranging from correction, cropping of the study area, to classification applied to land-based studies shares similar principles with the preprocessing, cropping, and masking steps used in chlorophyll-a image processing using SeaDAS. More recently, analysis of green open space needs based on population projections [11], which underscores the wide-ranging application of geospatial technology for both terrestrial and aquatic studies in supporting the planning and management of regional resources, including marine and fisheries resources in Aceh.

C. Oceanographic Dynamics and the Impact of the COVID-19 Pandemic

The COVID-19 pandemic, which has been ongoing since 2020, has raised new research questions regarding the impact of reduced human activity on aquatic environmental conditions. The study of the seasonal dynamics of mackerel fishing at the Cikidang Fishing Port, found that the impact of the COVID-19 pandemic was reflected in a significant decline in fish production during 2020–2021 due to reduced demand and disruptions to fishing activities, although, statistically, chlorophyll-a concentrations in that study did not show a significant influence on catch yields compared to sea surface temperature. These findings provide an important context: changes in human activity during the pandemic do not always correlate directly and simply with chlorophyll-a parameters, therefore, studies that specifically compare pre- and post-COVID-19 pandemic conditions using multisensor data [12].

III. Method

This study was conducted in the waters off Aceh, located in the northern part of Sumatra and directly bordering the Indian Ocean, the Strait of Malacca, and the Andaman Sea. This region was selected because of its dynamic oceanographic characteristics, which are influenced by the monsoon wind system, ocean currents, waves, and the interaction of water masses from the Indian Ocean and the Strait of Malacca. These conditions cause the productivity of the waters in the Aceh region to vary both spatially and temporally, as can be observed through the distribution of chlorophyll-a concentrations. The study location is shown in Figure 1.

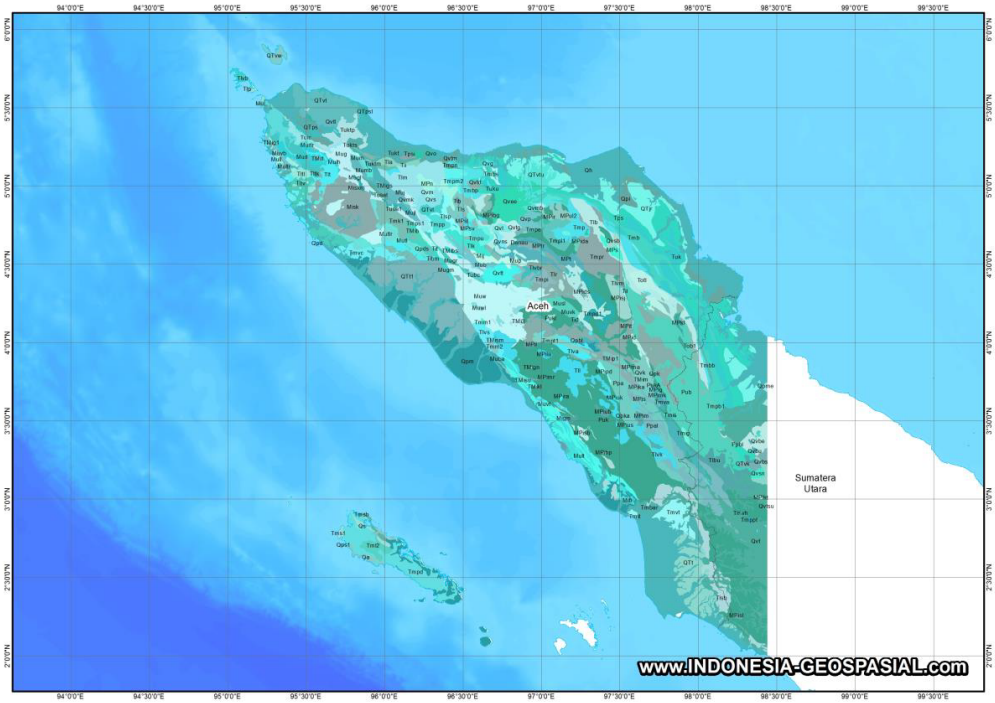

Fig 1. Map of the Research Location

The data used in this study consist of chlorophyll-a concentration data from Aqua MODIS and Terra MODIS satellite observations obtained from NASA Ocean Color (https://oceancolor.gsfc.nasa.gov/). The data product used is the chlorophyll-a (chlor_a) parameter, which serves as an indicator of phytoplankton abundance and primary productivity in the water.

This study used monthly data from July–December 2019 to represent conditions before the COVID-19 pandemic and data from January–June 2023 to represent conditions after the COVID-19 pandemic. These periods were selected to examine differences in chlorophyll-a distribution based on Aqua MODIS and Terra MODIS data under two distinct time conditions.

Table 1. Data processing was performed using SeaDAS

No	Satellite	Parameter	Period
1	Aqua MODIS	Chlorophyll-a	July-December 2019
2	Terra MODIS	Chlorophyll-a	July-December 2019
3	Aqua MODIS	Chlorophyll-a	January-June 2023
4	Terra MODIS	Chlorophyll-a	January-June 2023

Data processing was performed using SeaDAS (SeaWiFS Data Analysis System) version 7.3.2, software developed by NASA for processing oceanographic satellite data. SeaDAS was used for data visualization, delineating the study area, masking land areas, and extracting chlorophyll-a statistical data. In addition, Microsoft Excel was used for statistical analysis and creating comparison graphs.

This study was conducted through a series of systematic steps illustrated in the flowchart in Figure 1. Broadly speaking, the research process consists of five main stages: data collection, data processing using SeaDAS, data export, analysis using Microsoft Excel, and drawing conclusions.

[1] Satellite data collection,

Aqua MODIS and Terra MODIS image data covering the period before the COVID-19 pandemic (2019) and after the COVID-19 pandemic (2023). The data used are Level-3 chlorophyll-a concentration products obtained from the NASA Ocean Color Web.

[2] Data processing using SeaDAS software,

Involves five sequential sub-steps: (1) opening the data in HDF (Hierarchical Data Format), (2) subsetting or cropping the image according to the study area, (3) applying land masking to exclude land pixels from the analysis, (4) visualizing chlorophyll-a concentrations in the water area, and (5) extracting descriptive statistics, including the minimum, maximum, and mean values of chlorophyll-a concentrations.

[3] Exporting data and maps,

The results of SeaDAS processing—including statistical data and chlorophyll-a distribution maps—are exported for further analysis.

[4] Data processing using Microsoft Excel,

Including the creation of tables and graphs to visualize temporal trends and patterns in chlorophyll-a distribution. At this stage, a separate analysis of chlorophyll-a distribution was also conducted for each data source, namely Aqua MODIS 2019, Terra MODIS 2019, Aqua MODIS 2023, and Terra MODIS 2023.

[5] Comparison and analysis,

Comparing chlorophyll-a concentrations before and after the COVID-19 pandemic (2019 vs. 2023) to identify changes in water conditions related to changes in human activity during the pandemic period.

The statistical parameters used include the minimum, maximum, and mean values. The mean value is used as the primary parameter because it provides an overview of the general condition of chlorophyll-a concentrations in the study area.

The mean value is calculated using the following equation:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Notes:

$\bar{x}$ = average chlorophyll-a concentration (mg/m³)

xi = chlorophyll-a value at each observation

n = number of observation data points

To determine the change in chlorophyll-a concentration between 2019 and 2023, the percentage change was calculated using the following equation:

$$\text{Change (\%)} = ((X_2 - X_1)/X_1) \times 100\%$$

Notes:

X_1 = average value for 2019

X_2 = average value for 2023

The results of chlorophyll-a data processing using Aqua MODIS and Terra MODIS indicate variations in spatial and temporal distribution in the waters off Aceh during the observation period. These variations are evident from changes in chlorophyll-a distribution patterns as well as differences in average chlorophyll-a concentration values between 2019—the pre-COVID-19 pandemic period—and 2023—the post-COVID-19 pandemic period.

IV. Results and Discussion

The results of chlorophyll-a data processing using Aqua MODIS and Terra MODIS indicate variations in spatial and temporal distribution in the waters off Aceh during the observation period. These variations are evident in the differences in chlorophyll-a distribution patterns across regions, as well as changes in concentration values between 2019 and 2023. To understand the characteristics of chlorophyll-a distribution, an analysis was conducted on distribution maps and descriptive statistics, including minimum, maximum, and mean values for each observation period.

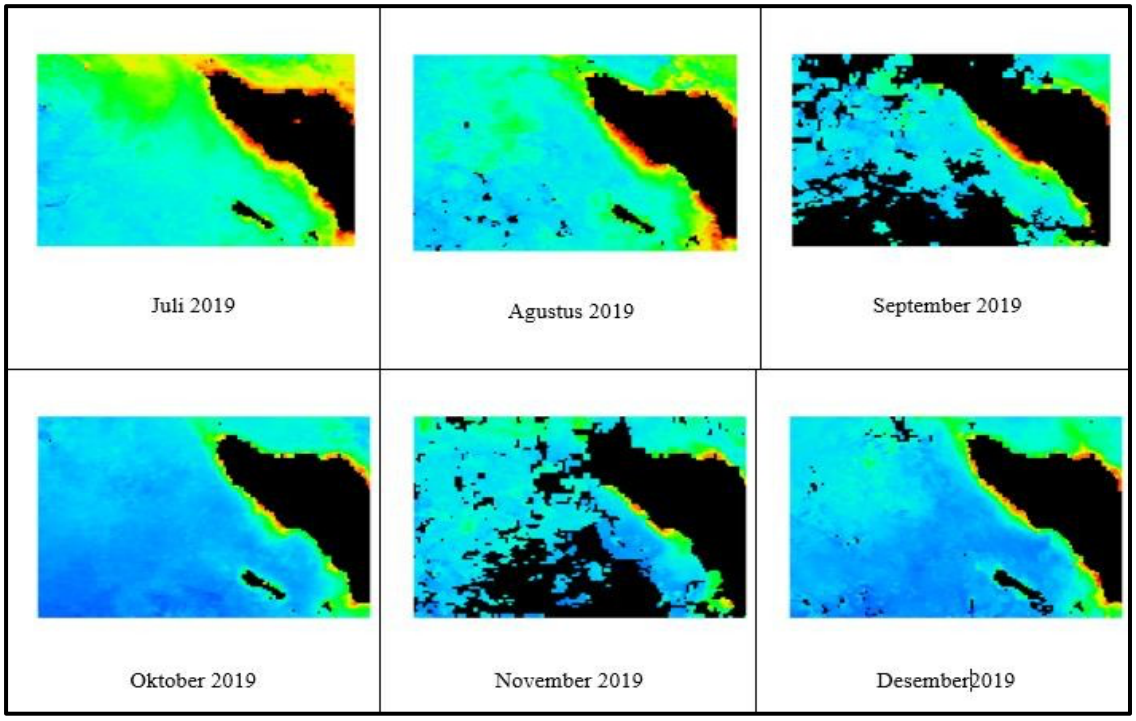

Fig 2. Aqua MODIS Chlorophyll-a Distribution for July–December 2019

Figure 2 shows that chlorophyll-a concentrations in 2019 tended to be higher in coastal areas than in offshore waters. This distribution indicates that the coastal areas of Aceh have higher water fertility due to nutrient inputs from the land. Nutrients carried by river flows play a significant role in promoting phytoplankton growth, as evidenced by the high chlorophyll-a concentrations.

In addition to the influence of the land, the high chlorophyll-a concentrations in some coastal areas are also thought to be influenced by water mixing processes and ocean current dynamics, which cause

nutrients from deeper layers to rise to the surface. These conditions support increased primary productivity, resulting in higher chlorophyll-a concentrations compared to offshore areas.

Table 2. Distribution of Aqua MODIS Chlorophyll-a Values for 2019

Month	Min	Max	Mean
July	0.0678	53.987	0.1799
August	0.0440	103.918	0.2163
September	0.0770	40.352	0.2150
October	0.0770	313.096	0.3157
November	0.0914	632.330	0.4462
December	0.0640	292.556	0.5280

Based on Table 2, the average Aqua MODIS chlorophyll-a concentration showed an upward trend during the July–December 2019 period. The average value increased from 0.1799 mg/m³ in July to 0.5280 mg/m³ in December. This increase indicates higher water productivity, which is believed to be related to oceanographic dynamics and nutrient availability in the surface layer.

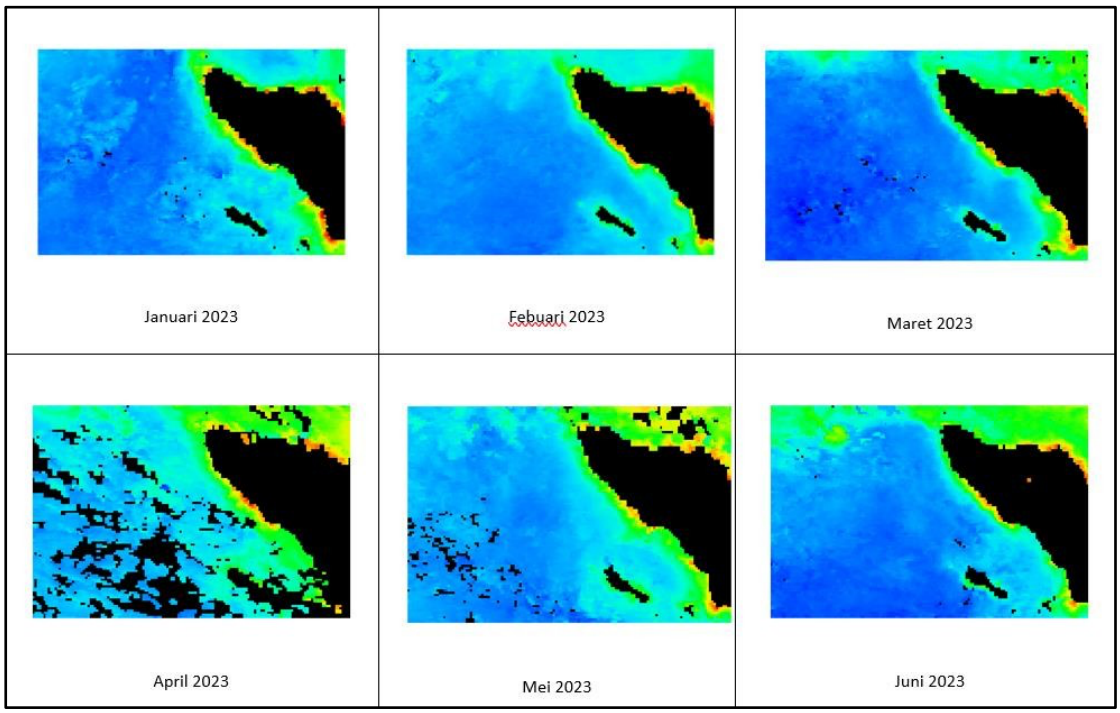

Fig 3. Aqua MODIS Chlorophyll-a Distribution for January–June 2023

The 2023 Aqua MODIS visualization results show that the distribution pattern of chlorophyll-a remains concentrated in the coastal waters of Aceh. However, compared to 2019, the intensity of chlorophyll-a distribution appears lower, indicating a change in the waters' productivity levels during the observation period.

Table 3. Aqua MODIS Chlorophyll-a Concentration Data for 2023

Month	Min	Max	Mean
January	0.0579	67.059	0.2865
February	0.0622	75.348	0.2397
March	0.0467	66.288	0.1993
April	0.0332	51.548	0.1731
May	0.0577	284.653	0.2006

June	0.0727	127.762	0.1893

The highest average value occurred in January at 0.2865 mg/m³, while the lowest value occurred in April at 0.1731 mg/m³. In general, the average values for 2023 were lower than those for 2019. This indicates a change in aquatic productivity during the observation period.

Differences in average values between months show that chlorophyll-a concentrations in the waters off Aceh fluctuated during the observation period. These fluctuations indicate dynamic changes in aquatic environmental conditions that affect the growth of phytoplankton, the primary producers of chlorophyll-a. In addition to the average values, variations in chlorophyll-a concentration can also be observed through changes in the minimum and maximum values for each month of observation. Analysis of these three parameters is important for providing a more comprehensive picture of the distribution characteristics of chlorophyll-a in the waters off Aceh during 2023.

Based on the distribution of Terra MODIS chlorophyll-a concentrations in 2023, the pattern was relatively stable, with average values ranging from 0.2067 mg/m³ to 0.2977 mg/m³. The highest value occurred in January at 0.2977 mg/m³, while the lowest value occurred in June at 0.2067 mg/m³. The patterns generated by Terra MODIS show good agreement with those from Aqua MODIS, although there are differences in values for some observation months. This indicates that both sensors are capable of accurately representing chlorophyll-a conditions in the waters off Aceh, but they exhibit different sensitivities to atmospheric conditions and the time of observation.

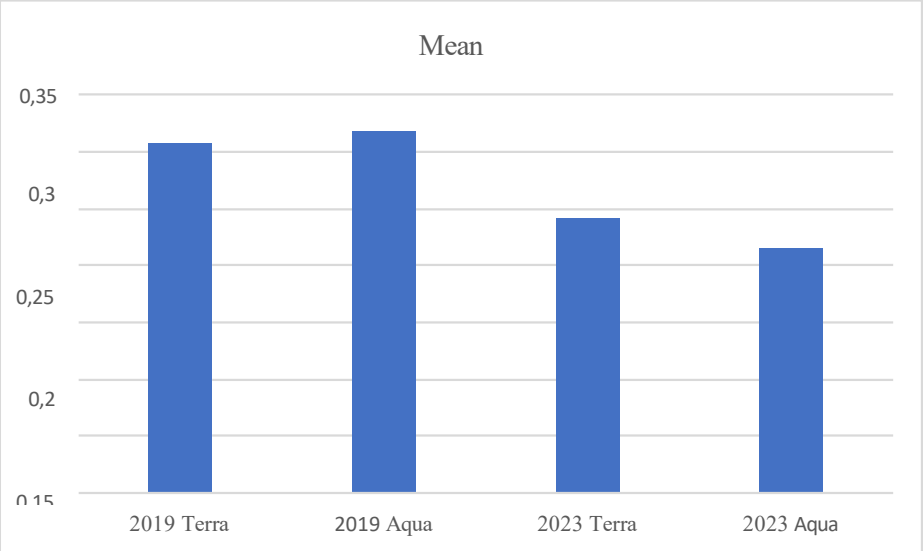

Fig 4. Comparison of Average Chlorophyll-a Values from Aqua MODIS and Terra MODIS in 2019 and 2023

Figure 4 shows that the average chlorophyll-a concentration in 2019 was higher than in 2023, based on both Aqua MODIS and Terra MODIS data. The average Aqua MODIS chlorophyll-a value in 2019 was 0.3169 mg/m³ and decreased to 0.2148 mg/m³ in 2023. Meanwhile, Terra MODIS data showed an average value of 0.3076 mg/m³ in 2019, which decreased to 0.2411 mg/m³ in 2023.

These results indicate a decrease in chlorophyll-a concentrations during the post-COVID-19 pandemic period. A decrease in chlorophyll-a levels may indicate reduced primary productivity in the water, which is related to the availability of nutrients for phytoplankton growth. However, changes in chlorophyll-a concentrations are influenced not only by human activities but also by oceanographic factors such as sea surface temperature, wind patterns, rainfall, ocean currents, and water mass mixing processes.

When compared based on the sensors used, Aqua MODIS showed slightly higher average values than Terra MODIS in 2019. Conversely, in 2023, Terra MODIS produced higher average values than

Aqua MODIS. This difference is believed to be influenced by the differing overflight times of the two satellites. Terra MODIS collected data in the morning, while Aqua MODIS collected data during the day, resulting in different atmospheric conditions and lighting during data collection. These differing conditions can affect the estimated chlorophyll-a concentrations derived from the satellite sensors.

To determine the magnitude of the change in chlorophyll-a concentration between 2019 and 2023, the percentage change in average values was calculated. The results show that Aqua MODIS recorded a decrease of 32.22%, while Terra MODIS recorded a decrease of 21.62%. The larger percentage decrease observed with Aqua MODIS indicates that this sensor recorded more significant changes in chlorophyll-a concentration compared to Terra MODIS during the observation period.

Spatially, both Aqua MODIS and Terra MODIS show relatively similar distribution patterns. Chlorophyll-a concentrations tend to be higher in coastal areas than in open waters. This indicates that the coastal waters of Aceh have higher water fertility due to nutrient inputs from land via river flows and water mixing in coastal areas. In contrast, open ocean areas have lower nutrient concentrations, resulting in lower chlorophyll-a values.

The results of this study are consistent with various previous studies showing that chlorophyll-a distribution in Indonesian waters is generally higher in coastal areas than in offshore waters. The high concentration of chlorophyll-a in coastal areas is closely related to high nutrient input, which supports the growth of phytoplankton as primary producers in marine ecosystems.

Overall, the results indicate that Aqua MODIS and Terra MODIS are capable of accurately depicting chlorophyll-a distribution patterns in the waters off Aceh. Both sensors produced relatively similar spatial patterns, although there were differences in concentration values during certain observation periods. Furthermore, there was a downward trend in chlorophyll-a concentrations in 2023 compared to 2019, indicating changes in water productivity conditions during the study period.

V. Conclusion

Based on the results of chlorophyll-a data processing and analysis using the Aqua MODIS and Terra MODIS satellites in the waters off Aceh, it was found that both satellite sensors showed relatively similar patterns of chlorophyll-a distribution. Chlorophyll-a concentrations tend to be higher in coastal areas than in offshore waters. These conditions indicate that the coastal waters of Aceh have higher water fertility due to nutrient input from land, water mass mixing, and other oceanographic factors that support phytoplankton growth.

The results of the study show that the average chlorophyll-a concentration before the COVID-19 pandemic (2019) was higher than after the COVID-19 pandemic (2023). Aqua MODIS data show an average value of 0.3169 mg/m³ in 2019, which decreased to 0.2148 mg/m³ in 2023. Meanwhile, Terra MODIS data showed an average value of 0.3076 mg/m³ in 2019, which decreased to 0.2411 mg/m³ in 2023. This decrease indicates a change in aquatic productivity conditions during the observation period.

A comparison between Aqua MODIS and Terra MODIS reveals differences in chlorophyll-a concentration values during certain observation periods. Nevertheless, both sensors still produce relatively similar distribution patterns, making them suitable for monitoring oceanographic conditions and aquatic productivity in the Aceh region. The differences in the values are believed to be related to variations in satellite overpass times, atmospheric conditions at the time of recording, and the observational characteristics of each sensor.

Overall, this study shows that Aqua MODIS and Terra MODIS data can be used to identify patterns in chlorophyll-a distribution and changes in aquatic productivity, both spatially and temporally. The results of this study are expected to serve as a source of information for the management of marine and fishery resources in the waters of Aceh, as well as a reference for further research examining the relationship between chlorophyll-a and other oceanographic parameters such as sea surface temperature, ocean currents, wind, and potential fishing grounds.

Future research is recommended to use a longer data period and to compare the same months or seasons across years in order to minimize the impact of seasonal variations on chlorophyll-a concentrations. In addition, the use of field (in situ) data for validation is necessary to improve the accuracy of satellite observations.

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