International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 54 No. 1 December 2025, pp. 577-583

Temporal Response Of Chlorophyll-A To Precipitation In The Coastal Waters Of Semarang City, Central Java

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Abstract - Semarang City, located on the north coast of Java Island, faces high environmental and anthropogenic pressures from industrial activities, agriculture, and dense settlements. These pressures have the potential to affect primary productivity in its waters, as indicated by the dynamics of chlorophyll-a (phytoplankton) concentrations. This study aims to analyze the temporal pattern of chlorophyll-a and its relationship to rainfall in Semarang City waters. The data used are the Ocean-Color Climate Change Initiative (chlorophyll-a) and Global Satellite Mapping of Precipitation (precipitation). The observation period in this research is daily data from January 2024 to December 2024. Monthly data analysis revealed a clear seasonal pattern: chlorophyll-a concentrations peaked during the West Monsoon (December-February), reaching approximately 2.4 mg/m³ in February, which correlated positively with high rainfall. This increase was driven by runoff, which carries nutrients and stimulates phytoplankton growth. Conversely, during the East Monsoon (June-August), chlorophyll-a concentrations decreased to 0.8 mg/m³ (October), likely due to water stratification and reduced nutrient supply. Statistical analysis revealed a moderate correlation (0.43) between rainfall patterns and chlorophyll-a, with a lag between peak rainfall (January) and peak chlorophyll-a (February). These findings indicate that Semarang waters are heavily influenced by nutrient inputs from land, making them vulnerable to eutrophication and potential algal blooms during the rainy season. Understanding these patterns is important for water quality early warning systems, sustainable fisheries management, and planning to mitigate the impacts of environmental degradation in densely populated coastal areas.

Keywords: Chlorophyll-a, Precipitation, Java Island, Semarang.

I. INTRODUCTION

Semarang City is located in the north of Java and faces environmental and anthropogenic pressures (Aditya and Ito, 2023). Environmental pressures are evident in various issues, such as increased waste generation, environmental degradation, rising sea levels, and others. Anthropogenic pressures stem from the intensity of industrial activity, agriculture, and dense settlements. All of these activities can impact primary productivity in Semarang City's waters (Nuzapril and Prasetyo, 2023). Primary productivity is the main foundation of the aquatic food chain. A frequently used indicator of primary productivity to assess aquatic health is phytoplankton (chlorophyll-a) (Thurman, 1997).

Chlorophyll-a is a pigment found in plants, found in all phytoplankton groups, and functions in the process of photosynthesis (Yun et al., 2019). Chemically, chlorophyll-a has the ability to absorb sunlight with wavelengths of 430-450 nm and 660-670 nm (Febriyanti et al., 2023). Waters with high chlorophyll-a can be characterized by the water turning green, a characteristic color of phytoplankton (Saleh and Halidun, 2022). Numerous previous studies have established a positive correlation between high chlorophyll-a concentrations in water and eutrophication, as well as decreased water quality (Rofi'ah et al., 2022). The increase in chlorophyll-a is influenced by the increase in nutrients in the sea caused by runoff from land.

Precipitation is a key driver of coastal carbon dynamics, connecting land and water. Indonesia, particularly Java, has two main seasons: the west monsoon and the east monsoon. The west monsoon is characterized by high rainfall and occurs between December

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and February. This time of year keeps the hydrological cycle running and influences the input of dissolved and particulate nutrients into water bodies through rivers. Meanwhile, the east monsoon is characterized by low rainfall and occurs between June and August. Based on the constantly changing weather anomalies caused by climate change, are the waters of Semarang also experiencing an increase in phytoplankton?

Understanding these temporal patterns has direct practical implications for water quality early warning systems, sustainable fisheries management, and mitigating the impacts of eutrophication in densely populated coastal waters. Analysis of the temporal relationship between rainfall and chlorophyll-a is expected to contribute to scientific understanding of coastal ecosystem resilience to environmental degradation and to planning for land-based waste management and conservation in Semarang waters.

Figure 1. The study is being conducted in the Central Javan city of Semarang. The river in Semarang City is shown by the blue line.

II. METODOLOGY

Chlorophyll-a data was collected from the European Space Agency's Ocean-Color Climate Change Initiative (OC-CCI) project (http://marine.copernicus.eu/). OC-CCI is a part of an ESA program to produce "climate-grade" essential climate variables based on satellite data. OC-CCI is composed of SeaWiFS, VIIRS, MERIS, MODIS-Aqua, and OLCI-S3A data using the best-performing atmospheric correction and chlorophyll algorithms ([Sathyendranath et al., 2019). The Root-Mean-Square Deviation (RMSD) reaches 0.34, indicating that the OC-CCI data have good accuracy (Garnesson et al., 2022). We used daily level 4 data with 0.04º spatial resolution interpolated to fill in missing data values. For the scope of this study, radar rainfall measurements are considered ground truth for rainfall information. The satellite rainfall product is the GSMaP standard product (GSMaP_MVK), version 7. GSMaP_MVK is the combined product from microwave and infrared rainfall measurements (Lee and Huang, 2023). GSMaP_MVK provides hourly precipitation rates (mm h−1) at 0.1° × 0.1° grid box with global coverage spanning from 60°N to 60°S (Fu et al., 2011). The observation period in this research is daily data from January 2024 to December 2024. Bathymetry and topography was obtained from national topography (DEMNAS) (https://tanahair.indonesia.go.id/portal-web/unduh/demnas).

All remote sensing data were analyzed on a monthly climatology basis following,

$$\bar{X}(x, y) = \frac{1}{n}\sum_{i=1}^{n} x_i(x, y, t)$$

Where X (x, y) is an average of the pixels data, xi(x, y, t) is the ith value of the data at position (x, y) and time (t). Furthermore, n is a number of data (i.e., from 2020 to 2023). xi is excluded from the calculation if that pixel has a missing data value.

The relationship between chlorophyll-a and precipitation is described in terms of the Pearson correlation (*r*). The correlation coefficients are calculated as follows (Zhu et al., 2021):

$$r = \frac{\sum(x_i - \bar{\bar{x}})(y_i - \bar{\bar{y}})}{\sqrt{\sum(x_i - \bar{\bar{x}})^2 \sum(y_i - \bar{\bar{y}})^2}}$$

where x and y are the chlorophyll-a and precipitation data, x and y are the average values, *n* is the number of matching chlorophyll-a and precipitation data. The Pearson correlation is used to describe the linear relationship between chlorophyll-a and precipitation data. After testing the hypothesis, the correlation coefficient is then interpreted to determine the strength of the correlation.

Table 1. Correlation strength categories (Prijana and Yanto, 2020)

Strength level	Categories
< 0.20	Slight (weak correlation)
0.20 -0.40	Low correlation
0.40 -0.70	Moderate correlation
0.70 -0.90	High correlation
0.90 -1.00	Very high correlation

III. RESULTS AND DISCUSSION

We analyzed the monthly chlorophyll-a and precipitation along the Semarang Waters region from January to December over the periods of each dataset. Figure 2 displays the spatial distribution of chlorophyll-a concentration in west monsoon (December, January, February) and east monsoon (June, July, August) (Aldrian and Susanto, 2003). We focus on west monsoon and east monsoon because variation of chlorophyll-a in this season clearly seen. The color variation from blue to red indicates a change in chlorophyll from lower to higher, thus facilitating the identification of chlorophyll-a dynamics between seasons. This pattern provides an overview of the dynamics of primary productivity in coastal areas throughout the seasons.

During the west monsoon (December–February), chlorophyll-a concentrations tend to increase in coastal areas, as indicated by the appearance of a green–reddish zone. This pattern indicates the contribution of land runoff, which carries nutrients to coastal waters, thus triggering an increase in phytoplankton. Conversely, more open waters appear to be dominated by blue, reflecting lower chlorophyll-a concentrations and relatively stable oligotrophic conditions. This is consistent with previous research on the influence of land runoff on chlorophyll-a in coastal areas (Kurniawan et al., 2023).

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During the East Monsoon (June–Aug), an obvious change occurs. In June and July, chlorophyll-a concentrations remain relatively high near the coast, but in August, a wider blue zone appears, indicating a decrease in chlorophyll-a concentrations. This pattern may be related to the strengthening of easterly winds, which increase stratification (Fitrianti et al., 2018) and reduce nutrient supply (Nufus et al., 2017).

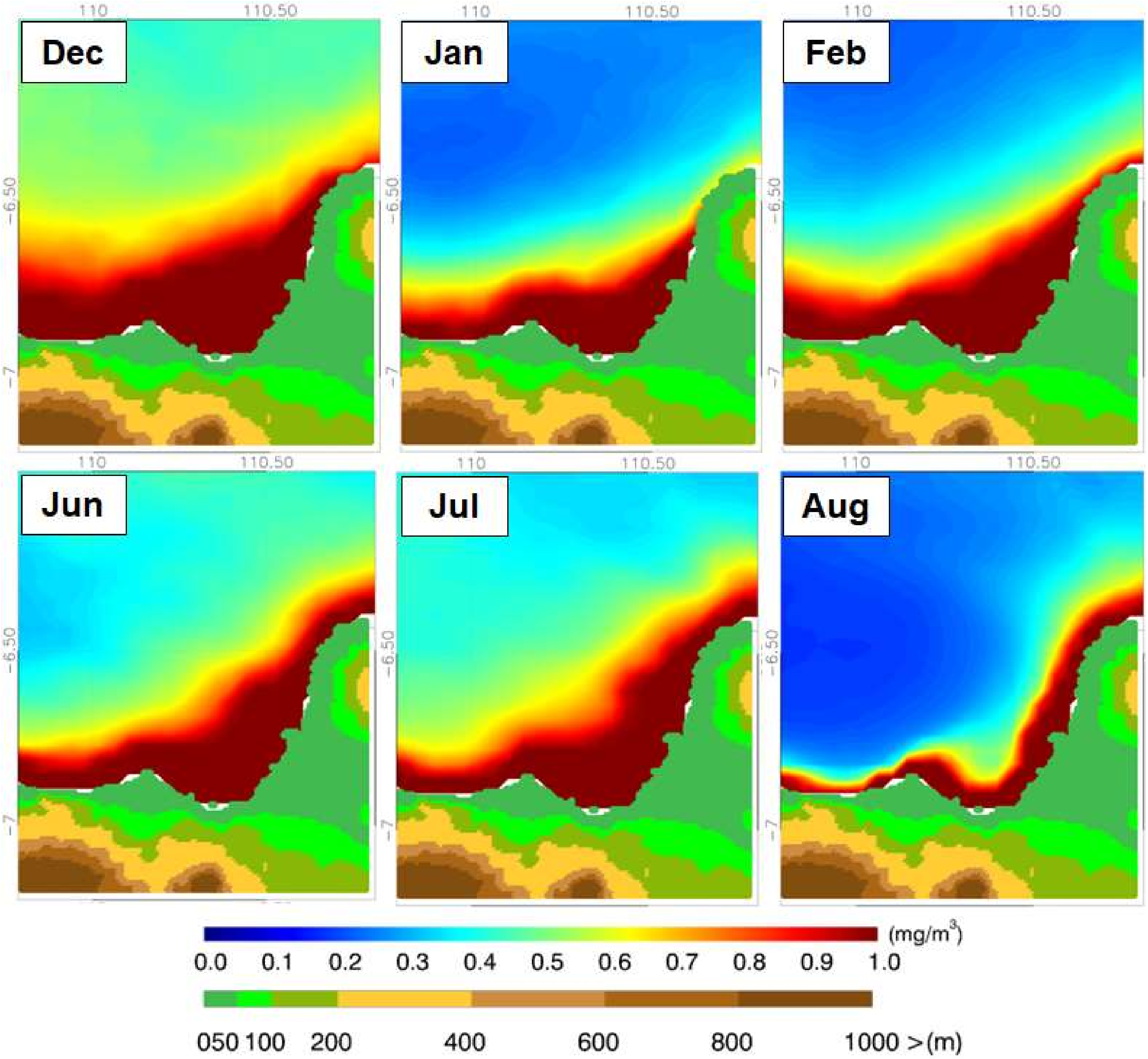

Figure 2. The spatial distribution of chlorophyll-a during the west monsoon (December, January, and February) and the east monsoon (June, July, and August) in the waters of Semarang City in 2024.

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The chlorophyll-a diversity observed between January and December reflects the significant influence of nutrient input on chlorophyll-a dynamics in coastal areas. Several studies have found that increased nutrient supply to the ocean is positively reduced by increased rainfall (Octavianna et al., 2025). Therefore, we analyzed rainfall to determine the cause of the increase in chlorophyll-a during the east monsoon. Understanding this seasonal pattern is important because it influences aquatic productivity, fisheries potential, and the potential for ecological anomalies such as blooms or drastic declines in phytoplankton biomass.

The graph of chlorophyll-a concentrations in Semarang City waters for 2024 (Fig. 3) reveals a changing temporal pattern throughout the year. The Chlorophyll-a concentrations reached a maximum in February at roughly 2.4 mg/m³, thereafter declining to about 2 mg/m³ in March. Following March, there was a sustained decrease until October (0.8 mg/m³). Chlorophyll-a concentrations subsequently increased in December by approximately 2 mg/m³.

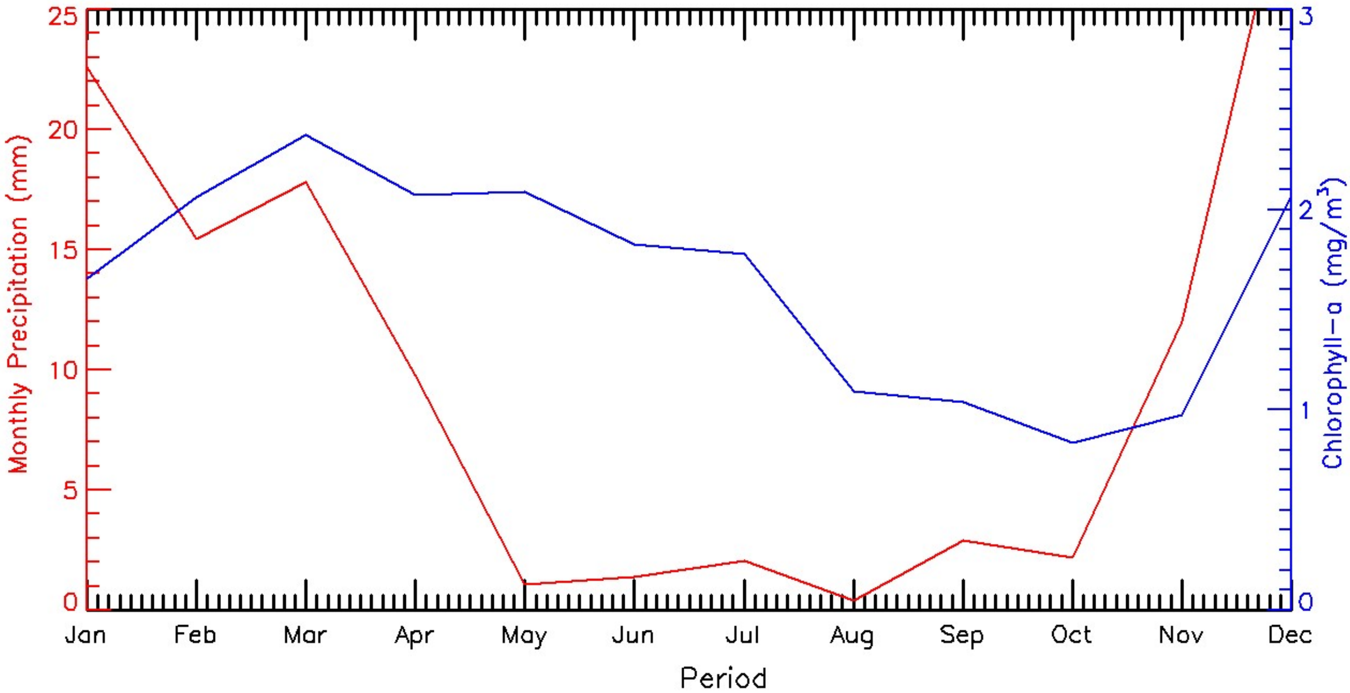

Figure 3. The monthly time series of chlorophyll-a (blue) and precipitation (red) in the seas of Semarang City for 2024.

The temporal pattern of chlorophyll-a exhibits a robust association with precipitation patterns in the Semarang region, with a correlation coefficient of approximately 0.43. The maximum chlorophyll-a concentration in February is strongly associated with the peak rainy season in the Semarang City region, occurring from December (25 mm0 to February (15 mm) (Fig. 3). Intense precipitation during this season results in heightened runoff from terrestrial surfaces, transporting nutrients including nitrogen and phosphate into coastal waters (Sudradjat et al., 2024). The process of augmenting chlorophyll-a by precipitation involves multiple stages: initially, significant rainfall induces erosion and surface runoff. Nutrients from anthropogenic activities, including agriculture, industry, and urban settlements, are transported into aquatic environments. Third, enhanced nutrient availability promotes phytoplankton proliferation (Wahyudi et al., 2025). The lag time between peak precipitation (January (24 mm)) and peak chlorophyll-a concentration (February (15 mm)) signifies the duration necessary for nutrient translocation and the biological reaction of phytoplankton. The significant reduction in chlorophyll-a concentration from April to October aligns with the dry season in Semarang City. In the dry season, decreased precipitation results in a decline of nutrient influx from terrestrial sources. Moreover, steady aquatic conditions and elevated solar intensity can induce stratification that restricts nutrient mixing from deeper layers

(Balkis-Ozdelice, 2003). The pattern of chlorophyll-a variations, characterized by a pronounced peak in the rainy season, suggests that the waters of Semarang are significantly influenced by nutrient influx from terrestrial sources. This signifies that the aquatic system is susceptible to eutrophication in the rainy season, potentially leading to a phytoplankton population surge (algal bloom) that may escalate into a Harmful Algal Bloom (HAB) (Bendib and Boutrid, 2024).

IV. CONCLUSION

Data analysis indicates that the fluctuations of chlorophyll-a concentrations in the waters of Semarang City present a distinct seasonal pattern, predominantly affected by changes in precipitation. During the West Monsoon (December-February), elevated chlorophyll-a concentrations in coastal regions are attributed to nutrient-rich runoff from terrestrial sources resulting from substantial precipitation, hence enhancing phytoplankton growth. Conversely, during the East Monsoon (June-August), chlorophyll-a concentrations typically diminish. Temporal patterns in 2024 substantiate this relationship, exhibiting a positive correlation between rainfall and chlorophyll-a (0.43), with the greatest precipitation occurring in January and peak chlorophyll-a in February. This trend suggests that Semarang's water system is significantly affected by nutrient influx from terrestrial sources, rendering it susceptible to eutrophication and possible algal blooms in the rainy season, but more stable and oligotrophic conditions typically prevail in the east monsoon.

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