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NORMALIZED FLUORESCENCE LINE HEIGHT (NFLH) VARIATION OVER MALAYSIA MARITIME (2003-2024)

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Abstract:

The main intention of this study is to investigate the spatial and temporal distribution of normalized Fluorescence Line Heights (nFLH) over Malaysia's maritime region from 2003 to 2024. The analysis utilized the monthly Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua, nFLH product, that could be freely accessed through the National Aeronautics and Space Administration (NASA)'s Geospatial Interactive

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Online Visualization and Analysis Infrastructure (GIOVANNI) system. Time average map that was developed for the period of 2003 to 2024 finds high nFLH values consistently observed along the coastal regions, particularly along the west coast of the Peninsular Malaysia and coastal zone of Sarawak. This area exhibits nFLH values ranging between 1.0 × 10^{-1} and 5.0 × 10^{-1} W m^{-2} μm^{-1} sr^{-1}. This finding correlates with an increment in phytoplankton activity driven by nutrient input from terrestrial runoff, particularly near the river mouth. During northeast monsoon season, an increment in the fluorescence levels, clearly seen over South China Sea and Sabah's coastal water. The increment mostly due to the nutrient influx from monsoon rain. In contrast, low fluorescence levels were observed during the inter-monsoon and southwest periods. A decline in nFLH values over the study period suggests a decrement in phytoplankton biomass. This finding highlights the significant role of the northeast monsoon in influencing the nutrient cycle and biological productivity over Malaysia's coastal waters.

Keyword:

GIOVANNI, Malaysia, MODIS, nFLH, Phytoplankton.

Introduction

Monitoring of phytoplankton activity, especially in coastal region is important to understand marine ecosystems. One of the reliable methods is using satellite derived product, normalised Fluorescence Line Height (nFLH). It commonly be used as a proxy to the presences of chlorophyll-a (Chll-a) which is a key indicator for the presence of phytoplankton biomass in the marine ecosystem (Gomaa et al., 2020). Phytoplankton distribution and abundance are strongly influenced by the environmental conditions such as nutrient availability, temperature and light. The use of nFLH enables researchers to detect any changes in the phytoplankton biomass over huge spatial and temporal resolution. It also can be used as an early detection of potential in environmental changes such as eutrophication and declining in water quality.

The strong positive correlation between chlorophyll fluorescence line height and chlorophyll concentration firstly pointed in late 1970s by Morel and Prieur (Morel and Prieur, 1977; Zhao et al. 2022). Generally, chlorophyll absorbs light and uses the energy to either drive photosynthesis, release it as heat or re-emit it as light (fluorescence) (Murchie and Lawson, 2013; Lu et al., 2024; Khan et al., 2025). In essence, the nFLH are significantly and linearly correlated with chlorophyll (Xing et al., 2007; Lu et al., 2016; Madani et al., 2024). The moderate resolution imaging spectrometer (MODIS) that is onboard the Terra satellite is the first satellite sensor used to measure global solar stimulated fluorescence (Gower et al., 2004). In the Malaysia water region, Usup et. al., (2012) have examined the bloom dynamics of *Pyrodinium bahamense* over Sabah and Sarawak water region. It's underscoring the need for phytoplankton monitoring in the coastal region. Siswanto and Tanaka (2014) conducted a decade-long analysis of phytoplankton biomass in the Straits of Malacca using the SeaWiFS dataset, highlighting the importance of remote sensing in capturing interannual variability. Further study by Hamzah et al., (2019) provides insights into the seasonal variability of phytoplankton during the northeast monsoon season in the Kuantan port area. Mohd-Din et al., (2022) have conducted a study on spatial-temporal variability of micro-phytoplankton community structure across the Strait of Johor, Malaysia. Sohaimi et al. (2024) have investigated the surface phytoplankton distributions over the Malacca Straits during the northeast and southeast monsoon seasons to understand the controlling factors of their dynamics. Azmi et al. (2025) conducted a study on the temporal bloom dynamics of the *dinoflagellate tripos furca* in the Penang straits. Meanwhile Mohd-Din et al. (2025) have conducted the most recent study on the diversity and distribution of micro-phytoplankton and harmful microalgae along the Malaysia littoral of the Malacca Strait and South China Sea.

Building on the above discussion, this study aims to characterize the spatial and temporal distribution of phytoplankton in the Malaysia maritime region by using MODIS nFLH dataset as a proxy for the phytoplankton. The spatial distribution will be assessed through the generation of area-averaged nFLH maps over the period of 2003 to 2024 to identify regions with high and low phytoplankton activity. This assessment is crucial to detect biologically productive zones. Meanwhile, the temporal dynamics will be examined using time series for the period of 2003-2024 to evaluate seasonal trends, interannual fluctuations and potential anomalies over the study period. The integration of spatial and temporal analyses will offer a more comprehensive understanding of phytoplankton variability and its environmental drives. The outcomes of this study are expected to contribute valuable baseline information to support marine ecosystem monitoring over Malaysia waters.

Study Area

This study was conducted over Malysia maritime. The study location spans latitudes 1.3^{O}N to 7.3^{O}N and longitudes 99.4^{O}E to 119.4^{O}E which encompasses the Malaysia Peninsula, Sarawak and Sabah. Malaysia has an extensive coastline of approximately 4809 km (not including small islands), which is 1972 km on the Malaysian Peninsula, 1035 km on Sarawak, and 1802 km on Sabah (Axelrod, 2010). This region experiences an equatorial climate with mean annual temperatures around 25.4^{O}C and rainfall exceeding 3000 mm, primarily influenced by the northeast and southwest monsoons (World Bank, 2023). These monsoonal dynamics influence coastal processes such as wave regimes, sediment transport and coastal erosion.

Methodology

During this study, data was obtained from Geospatial Interactive Online Visualization and Analysis Infrastructure (GIOVANNI) website. The methodology used in this study is as follow. Firstly, a monthly time averaged map for the period of 2003 to 2024 was created over the study area. This developed map is used to investigate the nFLH variation over the spatial domain for the entire study area. This map could offer profound insight into the long-term trend of phytoplankton distribution over the study area. After that seasonal area averaged map was constructed. The map will cover the main four seasons, which are December to January (DJF), March to May (MAM), June to August (JJA) and September to November (SON). DJF season is concurrent with the northeast monsoon season; meanwhile, JJA is concurrent with the southwest monsoon season. The seasonal map could provide the phytoplankton distribution

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according to each season. These two types of maps could represent the spatial phytoplankton distribution over the study area. In order to investigate the variation of phytoplankton in time domain, the yearly and seasonal time series for the study area was created. These time series could represent the phytoplankton variation in the time domain over the study area. The developed map and time series is the analysed thoroughly.

Result and Discussion

Time Averaged Map of Normalized Fluorescence Line Height

The first intention of this study is to investigate the spatial nFLH distribution over the study area for the period of 2003 to 2024. To achieve this goal, a time averaged nFLH map over the study area was constructed utilizing satellite data spanning from 2003 to 2024. Observation on this map shows that, high nFLH values were consistently observed along the coastal regions, particularly along the west coast of Malaysia peninsular and coastal zone of Sarawak. This area exhibits nFLH values ranging between 1.0×10^{-1} to 5.0×10^{-1} W m^{-2} μm^{-1} sr^{-1}. The highest nFLH are generally found along the shorelines and near the river mouths. The distribution could be clearly seen in the Figure 1 which is representing by the bluish to yellow colour. Based on the spatial distribution trend, almost yellowish colour located at the highly turbid water especially over the river mouth and shallow coastal water. This trend is likely associated with an elevated phytoplankton activity driven by nutrient input from terrestrial runoff. Anthropogenic activities in coastal zones, such as agriculture and urban development, may also contribute to nutrient enrichment, which stimulates biological productivity in this region. In contrast, the open ocean region such as South China Sea (SCS) regions, significantly lower nFLH value was recorded. The value is typically less than 1.0×10^{-1} W m^{-2} μm^{-1} sr^{-1}. This finding suggests lower photosynthetic activity in this area, which is due to the limitation of nutrients in these deeper and stratified waters.

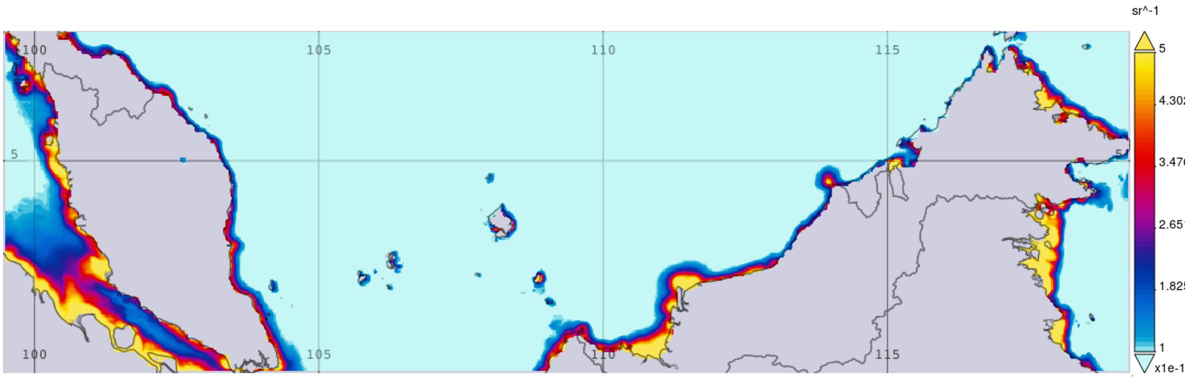

Figure 1: Time Averaged Map of Normalized Fluorescence Line Height (Water Only) Monthly 4 km [MODIS-Aqua MODISA_L3m_FLH vR2022.0] W m^{-2} μm^{-1} sr^{-1}.

Seasonal Averaged of Normalized Fluorescence Line Height

The previous section described the overall nFLH distribution. This section focuses on the spatial patterns of nFLH in relation to monsoonal variability, aiming to clarify the influence of the monsoonal season on the nFLH spatial distribution. Figure 2(a-d) shows the nFLH distribution for the DJF, MAM, JJA and SON seasons. Generally, the distribution is quiet the same as the overall distribution. The nFLH ranges also remain the same, which is in between 1.0×10^{-1} to 5.0×10^{-1} W m^{-2} μm^{-1} sr^{-1} for each season. However, as compared to the overall

International Journal of Innovation and Industrial Revolution
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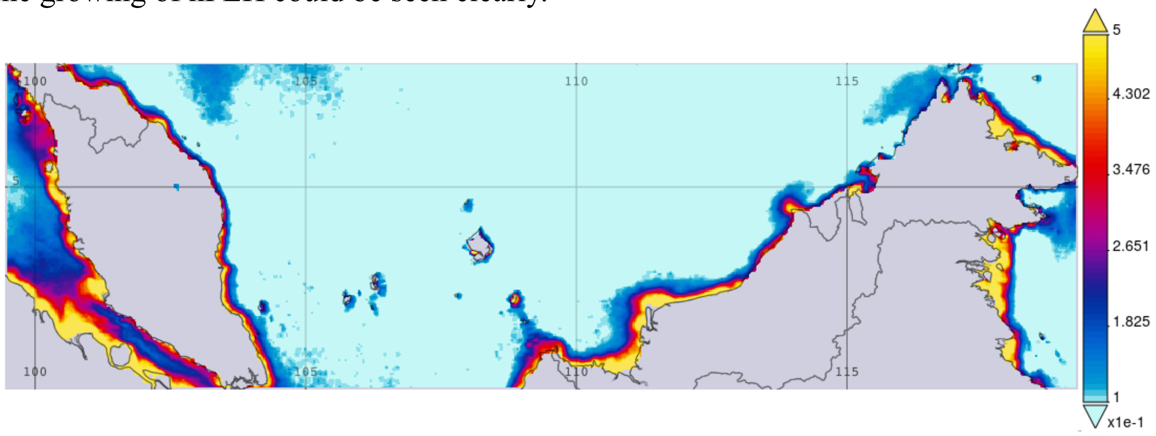
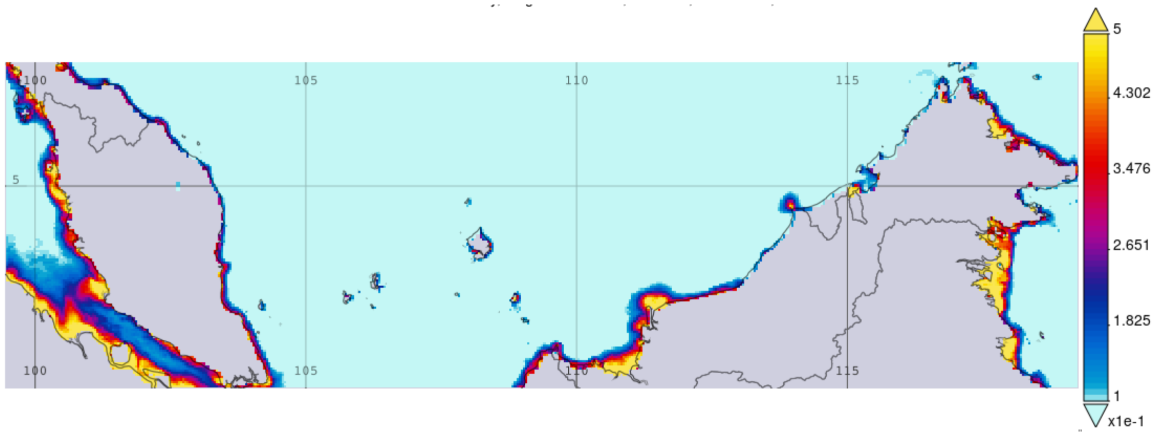
Volume 8 Issue 24 (March 2026) PP. 568-577

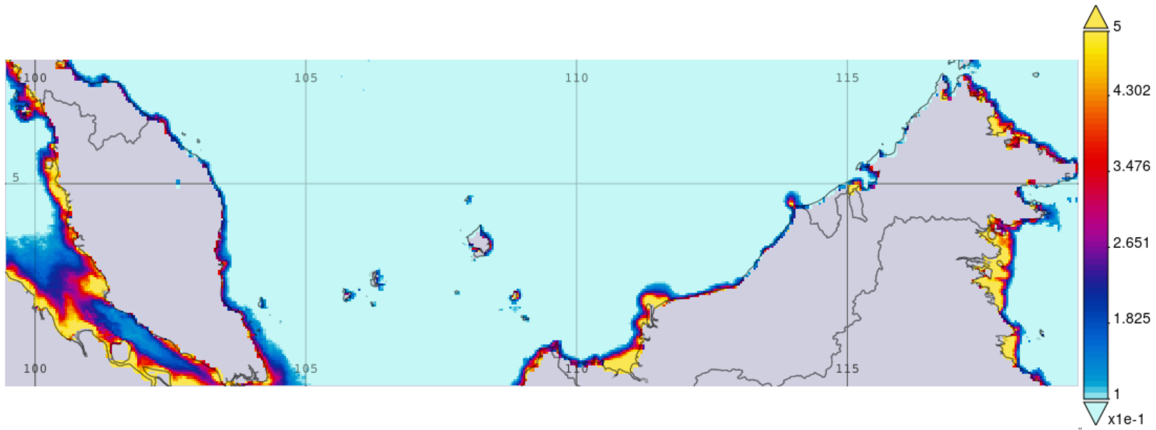
distribution, slight increment of nFLH clearly seen over SCS during DJF season. This is in conjunction with the Northeast Monsoon Season. The nFLH distribution could be detected as dark blue colour at the northeast of Malaysia peninsular. The heightened in the nFLH distribution also could be seen over Sabah coastal water. To the west of Malaysia peninsular, the growing of nFLH could be seen clearly.



December, January and February (DJF) Season



March, April, May (MAM) Season



June, July, August (JJA) Season

International Journal of Innovation and Industrial Revolution
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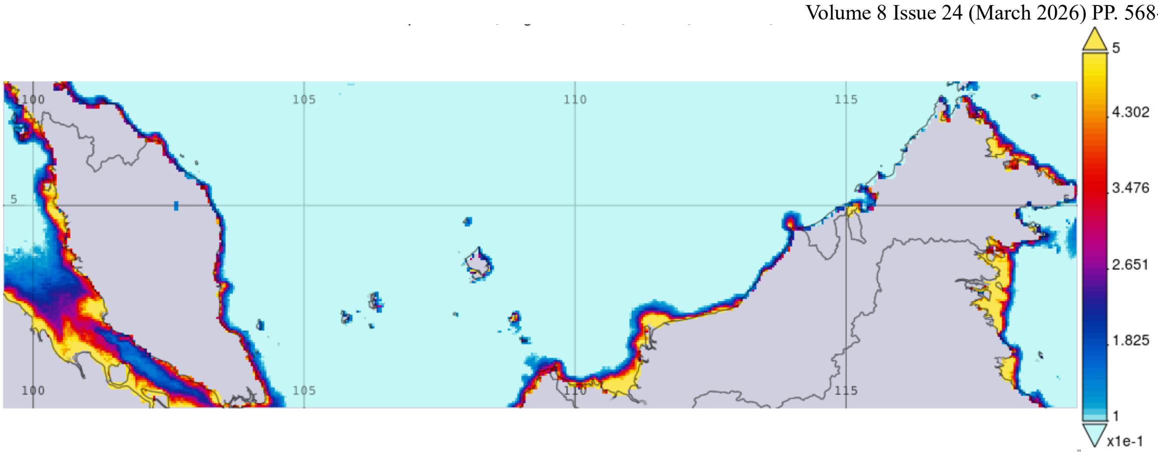

September, October, November (SON) Season

Figure 2: Seasonal Averaged of Normalized Fluorescence Line Height (a) December, January and February (DJF) season, (b) March, April and May (MAM) Season, (c) June, July and August (JJA) Season and (d) September, Oktober and November (SON) Season.

Interannual Time Series Average Normalized Fluorescence Line Height

The interannual time series of nFLH for the study area is illustrated in Figure 3. The nFLH values demonstrated noticeable variation over the 21-year observation period. the highest nFLH value was recorded in 2023, reaching 0.098 W m^{-2} m^{-1} sr^{-1}. In contrast, the lowest nFLH value occurred in 2023, measured at 0.079 W m^{-2} μm^{-1} sr^{-1}. The mean nFLH value across the study period was 0.087 W m^{-2} μm^{-1} sr^{-1} which is indicated by the red line in the figure. Based on Figure 3, 10 years (2003-2009, 2011 and 2015) exhibited values above average, while 12 years (2010,2012-2014, 2016-2020, and 2022-2024) exhibited values below the average. A negative trend is evident, as shown by the blue trendline with a slope of -0.0007. This negative slope suggests that declination the nFLH values over the two decades. This declining trend may be attributed to environmental changes, such as reductions in phytoplankton biomass or water quality degradation.

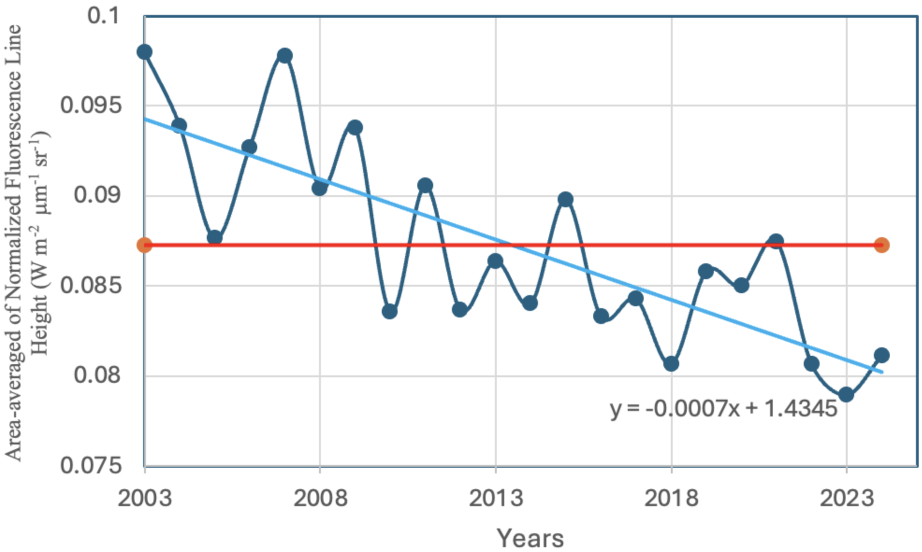

Figure 3: Interannual Time Series Average Normalized Fluorescence Line Height Monthly 4 km [MODIS-Aqua MODISA_L3m_FLH vR2022.0] W m^{-2} μm^{-1} sr^{-1}.

International Journal of Innovation and Industrial Revolution
IJIREV
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Figure 4 illustrates the seasonal variation of the nFLH over the period from 2003 to 2024 which is categories by four main seasons (December, January and February (DJF), March, April and May (MAM), June, July and August (JJA) and September, October and November (SON)). This graft is a reflection of biological processes, likely driven by changes in sea surface conditions, nutrient availability and atmospheric factors that influence nFLH levels in the coastal waters. Each season displays distinct patterns in the changes of the nFLH values throughout the study period. From the graph, it is obvious that DJF season shows a significant increase in the nFLH as compared to the other season. This season particularly aligns with the northeast monsoon in Southeast Asia, which typically occurs between November and March. During this season, Malaysia experienced heavy rainfall, cooler temperatures and an increase in humidity. These weather changes could significantly impact the biological and ecological processes, especially marine environment. Increment in the nFLH value could be partly attributed to the enhanced nutrient input into coastal waters due to monsoon rains. The heavy rainfall during this season can lead to nutrient runoff from the land, which may fuel plankton growth and increase fluorescence levels. The impact of the water mixing in the coastal zone could also contribute to more evenly distributed nutrients in the water column, providing optimal conditions for marine organisms involved in fluorescence.

During MAM season, with lower rainfall, the nutrient influx from river runoff also decreases, which leads to lower fluorescence due decrease in biological activity as compared to DJF. This condition remains consistent during the JJA and SON seasons. The seasonal nFLH patterns over Malaysia maritime are closely tied to the dynamics of the northeast monsoon, which plays a critical role in driving nutrient cycles and influencing the biological productivity of coastal ecosystems.

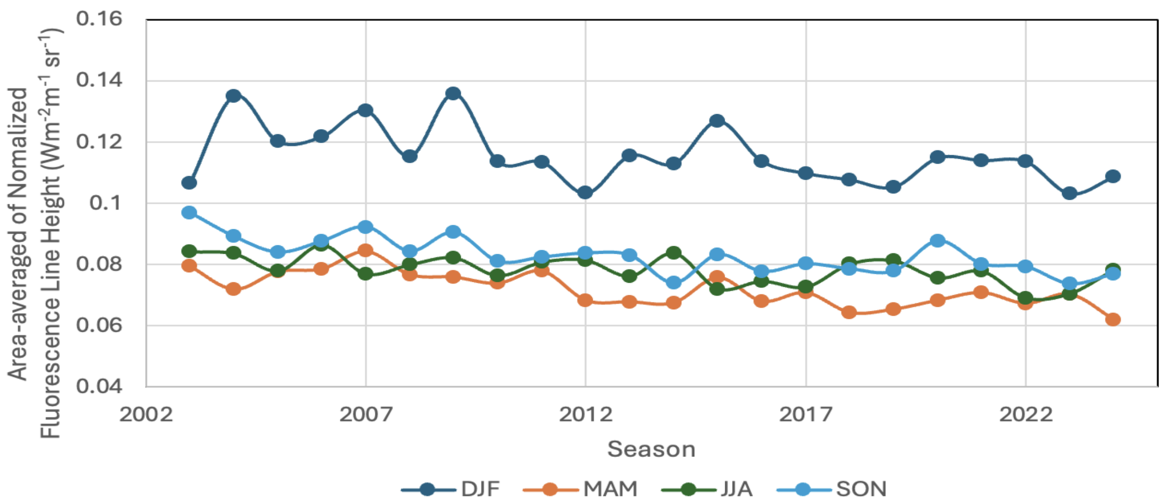

Figure 4: Seasonal Time Series Average Normalized Fluorescence Line Height monthly 4 km [MODIS-Aqua MODISA_L3m_FLH vR2022.0] W m^{-2} µm^{-1} sr^{-1}.

Conclusion

The primary goal of this study is to investigate the nFLH distribution over Malaysia's coastal waters from 2003 to 2024. The investigation is focusing more on spatial and seasonal variability. The results indicates that the highest nFLH values were consistently observed along the coastal regions, particularly along the west coast of Malaysia Peninsular and the coastal zone of Sarawak with values ranging from 1.0×10^{-1} to 5.0×10^{-1} W m^{-2} µm^{-1} sr^{-1}. The highest nFLH levels were found near shorelines and river mouths, likely due to increased phytoplankton activity driven by nutrient inputs from terrestrial runoff, especially in highly turbidity areas. The northeast monsoon season (DJF season) significantly impacts the nFLH distribution, which is leading to higher fluorescence levels in the South China Sea and Sabah coastal waters. The MAM, JJA and SON seasons, marked by lower rainfall and reduced nutrient influx, showed lower fluorescence levels as biological productivity decreased. The interannual analysis showed variability, with the highest nFLH recorded in 2023 and the lowest in 2019. The overall trend indicated a decline in fluorescence values over the study period, suggesting a potential decrease in phytoplankton biomass due to water quality degradation. The study highlights the crucial role of the northeast monsoon in driving nutrient cycles and affecting biological productivity in coastal ecosystems. Seasonal and interannual variations in nFLH reflect changes in sea surface condition, nutrient availability, and atmospheric factors that influence fluorescence levels in Malaysia's coastal waters.

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