Seasonal and Interannual Variability of Satellite-Derived Chlorophyll-a (2003-2019) in Lampung waters and surrounding area

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Abstract. In recent years, the phytoplankton blooming phenomenon occurred at Lampung Waters. This event harms living organisms due to its toxicity or caused oxygen depletion. Chlorophyll-a concentration (Chl-a) is the crucial biological parameter for simulating marine phytoplankton biomass. In this study, the monthly average of Chl-a ocean-color remote sensing data from 2003 to 2019 is investigated. The seasonal and interannual variability of Chl-a was analyzed in Lampung waters and its surrounding area. The study area was separated into three regions, namely the East Coast of Lampung waters, Lampung Bay and Sunda Strait area. The spatial pattern showed that the value of Chl-a on the east coast was higher than Lampung Bay and Sunda Strait, with a deal up to 7 mg/ m³. The time series of spatial averages in three areas showed the seasonal and inter-annual variation. The monthly climatology of Chl-a in Lampung Bay more influenced by sea surface temperature. The maximum value occurs in October with Chl-a concentration was 0.87 mg/m³. Meanwhile, the east coast area and Sunda Strait fit with the monthly rainfall pattern in the Lampung mainland. The maximum value occurs in February with Chl-a abundance were 2.49 mg/m³ and 0.96 mg/m³, respectively. The value indicated that the river runoff would be a significant impact on phytoplankton blooming. Otherwise, the interannual variability in three areas showed that the Lampung Bay was more influenced by Indian Ocean Dipole than the East Coast and Sunda Strait. The cross-correlation between Chl-a concentration and Dipole Mode Index in East Coast area, Lampung Bay, and Sunda Straits are -0.2, 0.5, and 0.1, with a significant level of 95%.

1. Introduction
Lampung waters characteristic can be explained in the form of tidal conditions, ocean currents, and sea surface temperature conditions. The waters in the west of Lampung have Formzahl (F) values in the range of 0.43-0.55, which means that the tidal type is mixed with double tide dominance. Likewise, the Sunda Strait and Lampung Bay have the same tidal type as West Lampung. Seasonal current conditions in the West Lampung Waters throughout the year flow from the southeast to the southwest with velocity ranging from 1 cm/s - 45 cm/s. The velocity of this current is the same as the current velocity in Lampung...
Bay Waters. In the Sunda Strait except for March, August, and October, currents generally move towards the Indian Ocean. Meanwhile, on the East Coast of Lampung, the current generally moves to the south with an average current velocity up to 45 cm/s [1]. The peak of southwest and northwest monsoon current velocity is 50 cm/s and 20 cm/s in The East Coast of Lampung waters [2][3].

The average monthly temperature (in the West part of Sumatra) ranges from 28°C - 29°C. In the geographical conditions of the bay waters that have direct access to the open waters of the Indian Ocean through the Sunda Straits. The distribution of sea surface temperature from satellite data and field data shows the dominance of 26.05°C-30.05°C, whereas the highest sea surface temperature in east Lampung was 33.5°C and the lowest was 29.4°C [1],[4],[5].

Harmful Algal Bloom (HAB) is blooming of algae and usually occurs in coastal areas. HAB phenomena is caused by blooms of microscopic algae, and it harms living organisms due to its toxicity or caused of oxygen depletion [6],[7]. There are two categories of HAB, namely toxin producer and red tide maker. Toxin procedures cause toxic properties that can accumulate in fish and shellfish. The uncontrolled abundance of pigmented phytoplankton populations which causes the color of seawater will change according to the pigment color of phytoplankton species, is called red tide maker. Red tide maker causes oxygen depletion and causes functional disturbances in fish, namely mechanical and chemical disturbances [8].

The HAB phenomenon in Lampung Waters had occurred in 2012 and 2017. The HAB phenomenon occurred in Hurun Bay, Lampung, which caused mass death of groupers in 2012. Meanwhile, the HAB phenomenon occurred in Lampung Bay in 2017. It affects to mass mortality of fish in Lampung Bay was caused by the increasing population of phytoplankton, namely red algae of the Cochlodinium polykrikoides type or commonly known as red algae, which has a very slimy characteristic [9],[10]. Chlorophyll-a concentration (Chl-a) is the crucial biological parameter and widely used for simulating or indicating marine phytoplankton biomass, as it can generally reflect the situation of phytoplankton growth [11],[12]. Thus, the purpose of this research are to analyze the abundance of phytoplankton by using Chl-a concentration in sea waters, and to examine the variability of Chl-a seasonal and inter-annual (2003-2019) based on spatial and temporal.

2. Materials and Methods

2.1. Study Area
Coastline of Lampung, including several islands, has approximately 1,105 km long and have about 69 islands. The coastal area is divided into four areas, namely the West Coast (210 km), Semangka Bay (200 km), Lampung Bay, Sunda Strait (160 km), and the East Coast (270 km) [13]. In this study, Lampung waters were divided into three areas: Lampung Bay, which was located on the west coast of Lampung province, East Lampung Waters, and the Sunda Strait.(Figure 1). The waters of Lampung Bay are one example of an area whose coastal areas are used for various activities such as fisheries, pearl cultivation, tourism, shipping, ports, settlements, and trade activities [1].

2.2. Data collection
The Chl-a data were acquired from Aqua Moderate Resolution Imaging Spectroradiometer (MODIS satellite). It has spatial resolution 0.05° x 0.05 ° with coverage 180°E to 180°W and 75°S to 75°N. This research analyses Chl-a patterns and variability were obtained using monthly Chl-a data from the mean values from 2003-2019. It available online at http://coastwatch.pfeg.noaa.gov/. The Sea surface temperature (SST) data derived from ERSST v4 SST in situ only. It has global spatial coverage with 2° x 2° grid resolution. The spatial and temporal monthly mean of SST generate and online available at https://climexp.knmi.nl/. The precipitation data derived from Climate Hazards Group Infrared Precipitation with Stations (CHIRPS). It is quasi-global satellite and observation-based precipitation
estimates over land. It has spatial resolution $0.05^\circ \times 0.05^\circ$ with time coverage from 1981-near real time [14]. Dipole Mode Index derived from HadISST1.1 using SST anomaly in area $10^\circ S-10^\circ N$ and $50^\circ E-70^\circ E$ minus $10^\circ S-0^\circ N$ and $90^\circ E-110^\circ E$ area averaged timeseries output created at National Oceanic and Atmospheric Administration (NOAA) Physical Sciences Laboratory (PSL). It available online at https://psl.noaa.gov/data/timeseries/DMI.

**Figure 1.** Lampung waters and its surrounding area. The sub-three area used on spatial average in time series analysis: (1) East Lampung Waters, (2) Lampung Bay, and (3) Sunda strait. (Source: GEBCO, 2014).

2.3. **Data Analysis**

Chl-a from ocean color satellite data derived using the algorithm developed by Hu et al [15]. MATLAB 2014 was used to calculate climatological mean, spatial and temporal data processing. The spatial plotting of Chl-a adopt script by Pawlowicz [16].
3. Results and Discussion

3.1. Spatial Distribution and Variability of Chl-a in Lampung Waters and Surrounding Area

In general, Chl-a in Lampung waters showed a higher concentration of Chl-a in coastal areas (East Lampung waters) and decreases gradually from the coast to the middle of the sea (Figure 2). The spatial pattern showed that the value on the east coast was higher than Lampung Bay and Sunda Strait, with deal up to 7 mg/m$^3$. Whilst the concentration of Chl-a values in the other two places tends to be small, the value was quite high in Lampung Bay with a value in the range of 3-4 mg/m$^3$, and the lowest value was in the Sunda Strait (1 mg/m$^3$). The highest concentration of Chl-a was in Lampung Bay, possibly due to the presence of nutrient inputs from rivers around the area. We know that nutrient input from rivers that are influenced by human activities will change the distribution of Chl-a. The seasonal (spatial) dynamics of Chl-a in Lampung Waters resulted in a growth process from October to March and deplete from April to September. The Chl-a values during the rainy season (September-March) were significantly higher (up to 7 mg/m$^3$) compared to the dry season (March-September). The highest value was in the range of 3-4 mg/m$^3$.

![Figure 2. Monthly climatology of Chl-a abundance (2003-2019) in Lampung waters and its surrounding waters area](image-url)
3.2. Seasonal Patterns of Chl-a in Lampung Waters and Surrounding Area

To gain more insight into seasonal variations of Chl-a over different locations, the Lampung Waters was divided into three sub regions. The time series of spatial averages in three areas shows the seasonal and inter-annual variation. The monthly climatology of Chl-a in Lampung Bay Influenced by sea surface temperature more than other aspects.

The results from this study showed that when the sea surface temperature was low, then the Chl-a concentration was high. This can be seen (Figure 3) in September and October when the temperature reached 28,16 and 28,63°C, the Chl-a values reached 0,79 and 0,87 mg/m³. Where this value was classified as a value with a high concentration (more than 0,7 mg/m³). Seasonal Chl-a concentration pattern in Lampung, Chl-a concentration in January in Lampung Bay was 0,42 mg/m³. The value continued to increase until June, which reached 0,61 mg/m³, and until the maximum value in October with Chl-a concentration is 0,87 mg/m³. After getting the peak of value, then the concentration decreases. Meanwhile, The East Coast Area and Sunda Strait fit with the monthly rainfall pattern in the Lampung mainland. During the dry season (March- September), especially in Lampung Bay, the concentration of Chl-a decreased, and vice versa during the rainy season (September-March), the value increased.

The value pattern between these places has a similarity. February is one of the rainy season peaks. The maximum value in February with Chl-a abundance is 2,49 and 0,96 mg/m³. The Chl-a values fluctuate, values fell and then rose again in June, namely 1,41 and 0,72 mg/m³, until the value continued to fall in the following months. Finally, the lowest value was in November, namely 0,96 dan 0,49 mg/m³. It indicated that the river runoff would have a significant impact on phytoplankton blooming.

When rainfall is high, the river discharge will also be high so that more nutrient inputs are carried away when compared to when precipitation is low. Moreover, if the soil conditions in the upstream area unable to withstand runoff even though the land cover is forest as happened in the upstream Ciliwung river, Bogor [17]. However, an anomaly still occurred in the rainy season. When the highest rainfall occurs in December, but the concentration of Chl-a in the East Coast and Sunda Strait is not the highest. It is even low compared to other months at 1,19 and 0,55 mg/m³. This could be due to many other factors that cause the value of Chl-a concentration apart from rainfall. Other factors include river discharge, temperature, salinity, turbidity, and ocean currents. For example, if there is a lot of nutrient input from land carried by river discharge, but no mixing occurs by ocean currents, then the concentration of Chl-a will not be high.

3.3. Chl-a inter-annual variation in Lampung Waters and Surrounding Area

The interannual variability in Indian Ocean such as Indian Ocean Dipole (IOD) influenced Southeast Tropical Indian Ocean (SETIO) [18],[19]. The interannual variability in three areas (Figure 4) shows that the Lampung Bay is more influenced by Indian Ocean Dipole than The East Coast and Sunda Strait [18]. The cross-correlation between Chl-a concentration and Dipole Mode Index in East coast area, Lampung Bay, and Sunda Straits respectively are; -0.2, 0.5, and 0.1, with a significant level of 95%.

The Chl-a abundance in Lampung Bay strongly influenced by IOD. It correlates with the ocean dynamic in this area. Some of physical parameter which affected to Chl-a concentration is sea temperature. The Lampung Bay has a strong influenced by Indian Ocean phenomenon such as IOD [18]. The East Coast of Lampung Bay and Sunda Strait did not strong correlation to Indian Ocean Dipole. It caused those area has a strong influenced by local forcing.
Figure 3. Monthly climatological mean of Chl-a concentration in Sunda Strait, Lampung Bay, and East Coast of area (a), Sea surface temperature in Lampung waters area (b), and precipitation in Lampung mainland area (c).
Figure 4. Dipole Mode (DM) Indian Ocean Index with red (blue) shading indicated DM+ and DM- (a), and Monthly mean of Chl-a concentration in Sunda Strait, Lampung Bay, and East Coast of area (b) during 2003-2019.

4. Conclusions
The spatial pattern of Chl-a abundance respectively to 7 mg/m3, 2 mg/m3, and 3 mg/m3 in East Coast of Lampung waters, Sunda Strait, and Lampung Bay. We found that the monthly climatological mean of Chl-a in the East coast of Lampung waters and Sunda Strait have a similar pattern. It fits with the monthly rainfall pattern in Lampung mainland. While the monthly climatological mean of Chl-a in Lampung Bay has a similar versa pater with sea surface temperature in Lampung waters. Then the inter-annual pattern of Chl-a in Lampung Bay fits with DMI. It has correlation 0.5 with a significant level of 95%. It indicated that Lampung Bay was strongly influenced by intra-annual variability in Indian Ocean.

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