



Impact Assessment of PSBB on Variations of NO₂, CO, and Chlorophyll-a Concentration in Java Island during the COVID-19 Pandemic based on Multi-satellite Imagery Data

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Submitted 6 Juni 2021. Reviewed 1 July 2021. Accepted 19 August 2021.

DOI: [10.14203/oldi.2021.v6i2.353](https://doi.org/10.14203/oldi.2021.v6i2.353)

Abstract

The enactment of the PSBB (Large-scale Social Restriction) on April to May 2020 due to COVID-19 pandemic, has reduced residents' activities, especially in Java Island, the most populous area in Indonesia with high anthropological activities. This policy may affect the conditions of atmospheric and water environment around the island of Java. NO₂ and CO concentrations in atmosphere along with chlorophyll-a concentration in the ocean are environmental indicators that can be observed through satellite imagery. Satellite data TROPOMI and CMEMS were used to investigate the variation of those concentrations in the atmosphere and ocean during PSBB. Oceanographic and atmospheric daily data of each parameter over the Java Island region were retrieved and merged into gridded data with 1 km spatial resolution to be compared. Variations of chlorophyll-a concentration within the same month over the previous years were also taken into account. NO₂, CO, and chlorophyll-a concentration were fluctuating during the PSBB period, but tended to decrease in the early phase of PSBB. The higher concentration of chlorophyll-a concentrated in the northern coastal areas of Java Island. In Jakarta and Surabaya, chlorophyll-a concentrations value during April-May 2020 were decreased by 48% and 27% compared to the previous three years' averages. Human activities were thought to be the main factor influencing variations in the concentration of NO₂, CO, and chlorophyll-a during PSBB enactment.

Keywords: Chlorophyll-a, satellite imagery data, PSBB, CO, NO₂.

Abstrak

Kajian dampak PSBB terhadap variasi konsentrasi NO₂, CO, dan klorofil-a di Pulau Jawa selama masa pandemi COVID-19 berdasarkan data multi-citrasatelit. Berlakunya masa PSBB (Pembatasan Sosial Berskala Besar) selama bulan April hingga Mei 2020 pada masa pandemi telah mengurangi aktivitas warga, khususnya di Pulau Jawa, pulau dengan populasi terpadat di Indonesia yang mempunyai kegiatan antropologis tinggi. Kebijakan PSBB diduga dapat mempengaruhi kondisi lingkungan udara dan perairan di sekitar Pulau Jawa. Konsentrasi NO₂, dan CO, di udara, serta konsentrasi klorofil-a di perairan merupakan beberapa indikator lingkungan yang dapat diamati melalui citra satelit. Data satelit TROPOMI dan CMEMS digunakan untuk mengetahui variasi konsentrasi yang ada di atmosfer dan laut selama PSBB. Data harian setiap parameter di wilayah Pulau Jawa diambil dan digabungkan menjadi data grid dengan resolusi spasial 1 km agar dapat dibandingkan dengan baik. Variasi konsentrasi klorofil-a dalam bulan yang sama pada tahun-tahun sebelumnya juga ikut diperhitungkan. Perubahan konsentrasi NO₂, CO, dan klorofil-a selama periode PSBB bersifat fluktuatif, namun cenderung menurun pada fase awal PSBB. Di

Jakarta dan Surabaya, terjadi penurunan nilai klorofil-a pada bulan April-Mei sebesar 48% dan 27% dibandingkan nilai rata-rata tiga tahun sebelumnya. Aktivitas manusia diduga menjadi faktor utama yang mempengaruhi variasi konsentrasi NO₂ dan CO di udara dan konsentrasi klorofil-a di perairan selama adanya pemberlakuan PSBB.

Kata kunci: Klorofil-a, multi data satelit, PSBB, CO, NO₂.

Introduction

The covid-19 pandemic caused by the SARS-Cov-2 virus had been spread over countries on a global scale. The first pandemic was shown in Wuhan, China, in December 2019 (Zhu et al., 2020); meanwhile, in Indonesia, the virus has been found in early March 2020 (Tosepu et al., 2020). In the beginning, local government recommended doing social and physical distancing to stop the spreading among the society (Yulianti et al., 2020). The Indonesian government announced PSBB as one policy to restrain virus spreading instead of implementing lockdown to prevent further disease. PSBB, known as *Pembatasan Sosial Berskala Besar* or Large Scale Social Restriction, is expected to protect people from virus infection by reducing human activities as minimizing crowd in school, workplace and prevent association of a large number of people in public space. The regulation excludes offices that provide necessary services for the community. Urgent activity is allowed as long as people stick to the health protocol as government-issued. The government demands people to stay more in their homes and do any activity, study, or work from home. PSBB is likely more flexible than the lockdown, so the government, industrial sector, and national economy keep functioned properly (Disantara, 2020).

The Java Island is the most populous island in Indonesia was accompanied with various anthropogenic activities. The rate of covid-19, which has increased rapidly, made PSBB policy was enacted intensely, particularly in the capital city and several most infected region. As a result, this policy enforces less human appeared in public spaces and is responsible for shifting the society and economy (Olivia et al., 2020). Moreover, reducing human activities due to PSBB affects the environment and emissions, such as decreasing daily fuel consumption and less industrial and agricultural activity. The changing of human behaviour was also leads to the atmospheric condition, which also will affect to the ocean or vice versa, even in local scale and short temporal scale (Berner & Berner, 2012). Therefore, the effect of any covid-19 prevention policy on the

environment becomes a new interest for researchers.

Satellite imagery is one option to monitor the atmosphere and ocean changes, especially in the pandemic periode, while survey activities were too risky to conduct. In addition, satellite technology can obtain data for larger areas in shorter time. Ocean parameters, such as sea surface temperature, chlorophyll-a concentration, and total suspended matter can be covered with this technological approach. However, due to its orbital time and cloud cover, it is familiar to merge all available satellite data to complete the gap, known as multi-satellite imagery data. Many satellites had been supported by specific sensors and empirical approaches to determine anthropogenic emissions, such as CH₄, CO, CO₂, NO₂, SO₂. Those emissions could affect the ocean due to atmosphere-ocean interaction. In Indonesia, several research were carried out using satellite data imagery such as monsoonal coastal process through SeaWiFS sensor satellite (Hendiarti et al., 2004), spatial and temporal pattern of chlorophyll-a studies (Syahdan et al., 2014), and chlorophyll-a distribution through satellite MODIS (Winarso & Marini, 2017).

The changes in atmospheric conditions might indirectly affect to the chlorophyll-a concentration. It is assumed that the nutrient concentration in the ocean is also changed through air-sea interaction. Naturally, nitrogen and carbon enter the sea through atmospheric deposition and N₂ fixation. Meanwhile, due to anthropogenic perturbation, atmospheric chemical compounds enter the ocean after the emission absorbs by the land or wet disposition from acid rain, and carried away by groundwater or river (Gruber & Galloway, 2008; Zaehle, 2013). The increasing nutrient and carbon components in the ocean will affect the photosynthesis activities and phytoplankton growth. This condition will be beneficial for a marine living, so that the primary productivity will increase alongside the increase of chlorophyll-a concentration. The deposition of atmospheric components such as atmospheric dust also contributes to the input of macro nutrients (phosphorus, nitrogen, iron, and silicon) to the surface waters of the seas and oceans (Varenik & Kalinskaya, 2021). Varenik & Kalinskaya (2021)

also observed that the influx of nutrients from the atmospheric depositions can increase chlorophyll-a concentration by 11–36% in the Black Sea region.

The ocean-atmosphere component during this pandemic is varying across the world. Panda et al. (2021) show a significant reduction of primary pollutants in Bhubaneswar, India, such as NO_x with 67% lower. The reduced traffic pollution and anthropogenic activities during lockdown periods led to better air quality. Emission reduction was also found within the lockdown in Argentina. Greenhouse gas emissions reduced up to 90%; meanwhile, NO_x , CO, and SO_x emissions reduce 160% compared to the previous year in the same month (Bolaño-Ortiz et al., 2020). The advantages of the pandemic event were a significant reduction in industrial activities led to pollution reduction in Boukhalef river, Morocco (Cherif et al., 2020). The changes during lockdown are pretty remarkable; not only the water changing is visible through level-3 satellite, but also the increasing quality of coastal water was observed.

Java Island is one region with human-related activities, including transportation and industry, that affect pollution to the atmosphere. Also, many rivers on this island were bring many components from housing, farming, and industry which lead to the ocean, will likely affect the coastal water. The PSBB indeed influences the environment temporarily, but the impact is necessary to be investigated further. This study aims to observe the variation of NO_2 , CO, and chlorophyll-a concentration in Java Island due to the government action taken through PSBB enactment.

Methodology

In this study, the Java Island region is studied over $104^\circ - 116^\circ \text{ E}$ and $5.5^\circ - 9^\circ \text{ S}$. Daily data of chlorophyll-a concentration and monthly data of primary productivity were retrieved over Java Island region from CMEMS. Meanwhile, atmospheric data, particularly NO_2 and CO were obtained from the TROPOMI Sentinel 5P project. These two parameters commonly represent anthropogenic emissions from the mainland. All historical data were collected in pre-PSBB and early PSBB time. A total data of two months was retrieved starting from April to May 2020. Since the PSBB date was different at each city or region in Java Island (Table 1 and Figure 1), thus in this study, it was assumed that PSBB started in the middle of April. It was reasonable since all the regions had enacted PSBB for their region at that time. Post-PSBB was not considered yet since several regions tend to extend their policy regarding the covid-19. A spatial map of all parameters observed was averaged every two weeks from the initial time. It was assumed that atmosphere and ocean interaction would take time; therefore, the dynamical change could be seen clearly in two weeks. In addition, each satellite captures data on its trajectory, which is regularly shifted, so it cannot capture all the observation areas. To obtain complete data, two weeks is considered sufficient to avoid data gaps by combining daily satellite imagery data. Both atmospheric and ocean data were compared to reveal their correlation, particularly before and after PSBB action. The time series of each parameter was compared statistically over time. A brief flowchart of this study can be seen in Figure 2.

Tabel 1. Tanggal inisiasi pemberlakuan PSBB di beberapa daerah Pulau Jawa
Table 1. Initial date PSBB enactment of several regions in Java Island.

Region	Province	Initial date of PSBB
DKI Jakarta	DKI Jakarta	10 April 2020
Bekasi, Bogor, Depok	West Java	15 April 2020
Tangerang	West Java	18 April 2020
Bandung, Cimahi, Sumedang	West Java	22 April 2020
Tegal	Central Java	23 April 2020
Surabaya, Sidoarjo, Gresik	East Java	28 April 2020
several places in Jawa Barat	West Java	11 May 2020
Malang, Batu	East Java	17 May 2020



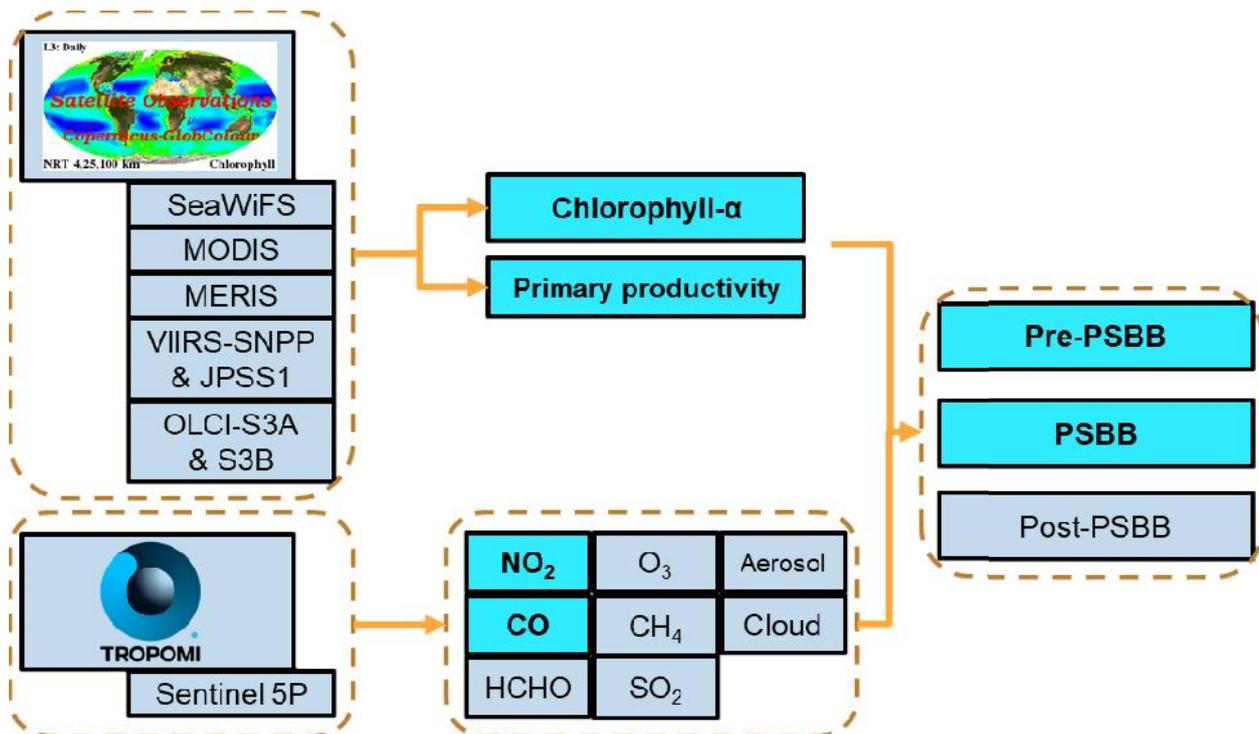
Gambar 1. Lokasi kota-kota yang melaksanakan pemberlakuan PSBB di Pulau Jawa. Tulisan tebal menandakan provinsi

Figure 1. Location of cities with PSBB enactment on Java Island. Bold text indicates province

CMEMS covered ocean data for global-scale, including Indonesian water. They provide modelling data and observation data, either from in-situ or satellite data. Time series data of ocean parameters, such as temperature, salinity, current, wave, carbon, and nutrient had been produced spatially with a certain resolution. All related data can be retrieved freely from <https://marine.copernicus.eu>. For this research purpose, chlorophyll-a concentration and primary productivity from multiple sources were retrieved. Satellite data on SeaWiFS, MODIS, MERIS, VIRSS-SNPP, JPSS-1, OLCI-S3A, and OLCI-S3B are combined in CMEMS which was then used to analyze changes in chlorophyll-a concentration and primary productivity. S3B sensors data. Each satellite has its characteristics, particularly the swath area and time in obtaining the surface data. Thus, the multi-satellite imagery data method is commonly used to fill the blank data and made the information was less uncertain. CMEMS collecting those available sources of the level-2 satellite imagery and turns the data into level-3 and level-4 with 4 km grids. The daily chlorophyll-a concentration data were retrieved in gridded data with the finest resolution (4 km 0.04175°). Besides that, primary production is closely related to chlorophyll-a concentration; thus, this data were also downloaded for further investigation. The gridded data then were downsampled into 0.005° (1 km) with simple interpolation method since some coastal area in Java Island was not covered with CMEMS data. Each daily data was then compared with

atmospheric concentration (NO_2 and CO). For spatial maps, marine data were averaged within two weeks to be compared in the PSBB phase (Pre-PSBB, late April, early May, and late May). Daily data for the same month (April and May) in the previous years (2017-2019) were also observed, so that variations between years can be compared.

The collaboration between European Space Agency (ESA), European Commission, Netherlands Space Office, industry, data users, and scientists created the Copernicus Sentinel-5 Precursor mission in monitoring our atmosphere. The mission was carrying the TROPOspheric Monitoring Instrument (TROPOMI) instrument in one satellite. The retrieved data was mainly atmospheric data, such as concentration of NO_2 , CO, HCHO, O_3 , CH_4 , SO_2 , aerosol, and cloud. The level 2 data of NO_2 and CO concentrations had been taken in Java Island region. Level-2 data contained swath data in each satellite's track. Although the data has a good resolution, the data is distributed following the satellite's track. Therefore, to get daily data, the existing data must be mapped uniformly into the data grid for easy comparison at all points. Similar to the previous parameters, the NO_2 and CO data were downgraded into 0.005° horizontal resolution. Then, the atmospheric data are averaged within two weeks for a spatial map to be compared within PSBB phase over Java Island. Daily data from TROPOMI only covers a few areas of Java Island, so it takes one to two weeks of combined data until the island is fully observed by satellite



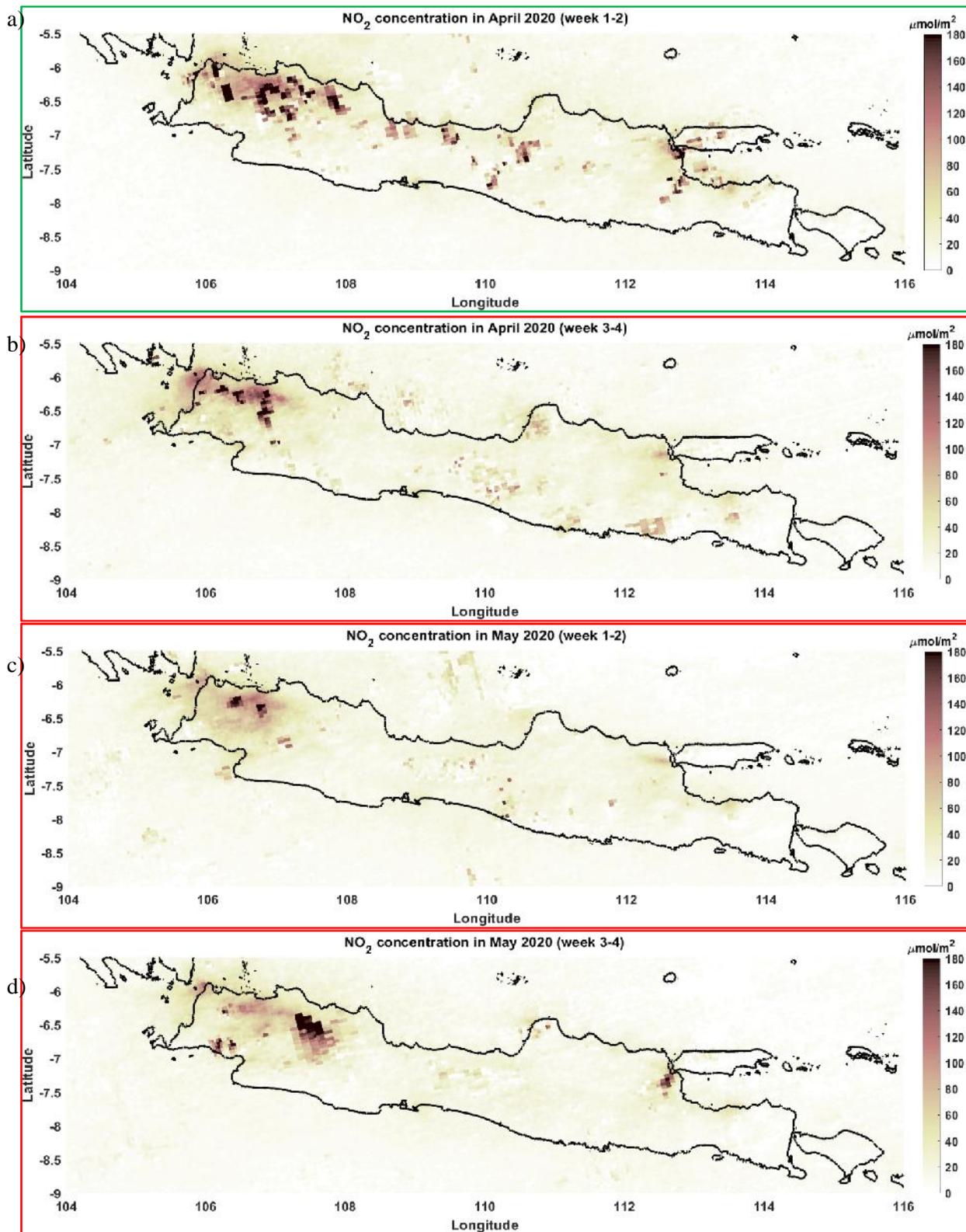
Gambar 2. Metodologi singkat mengenai data multi satelit
Figure 2. Brief methodology of multi-satellite imagery data

Results

The atmosphere and ocean parameters result from multi-satellite imagery data were visualized in a two-dimensional map over the study area. NO₂ average concentrations (Figure 3) were high in certain regions in Java Island, particularly in West Java and Jakarta region. The green box outside the map indicates the pre-PSBB, meanwhile red box indicates the earlier phase of PSBB. This study defines a high concentration above 140 $\mu\text{mol}/\text{m}^2$, while a low concentration is below 60 $\mu\text{mol}/\text{m}^2$. In the pre-PSBB, Jakarta, Bekasi, Depok, Tangerang, and Bogor have a high NO₂ concentration compare to other regions. Several points with moderate concentration were also indicated in central Java and Surabaya. Higher concentrations were likely to be found in larger cities. In the previous PSSB (week 3-4 April), the concentration was reduced, which was seen with the replacement of the high concentration area. Concentrations declined more in early May; but only concentrated in Tangerang,

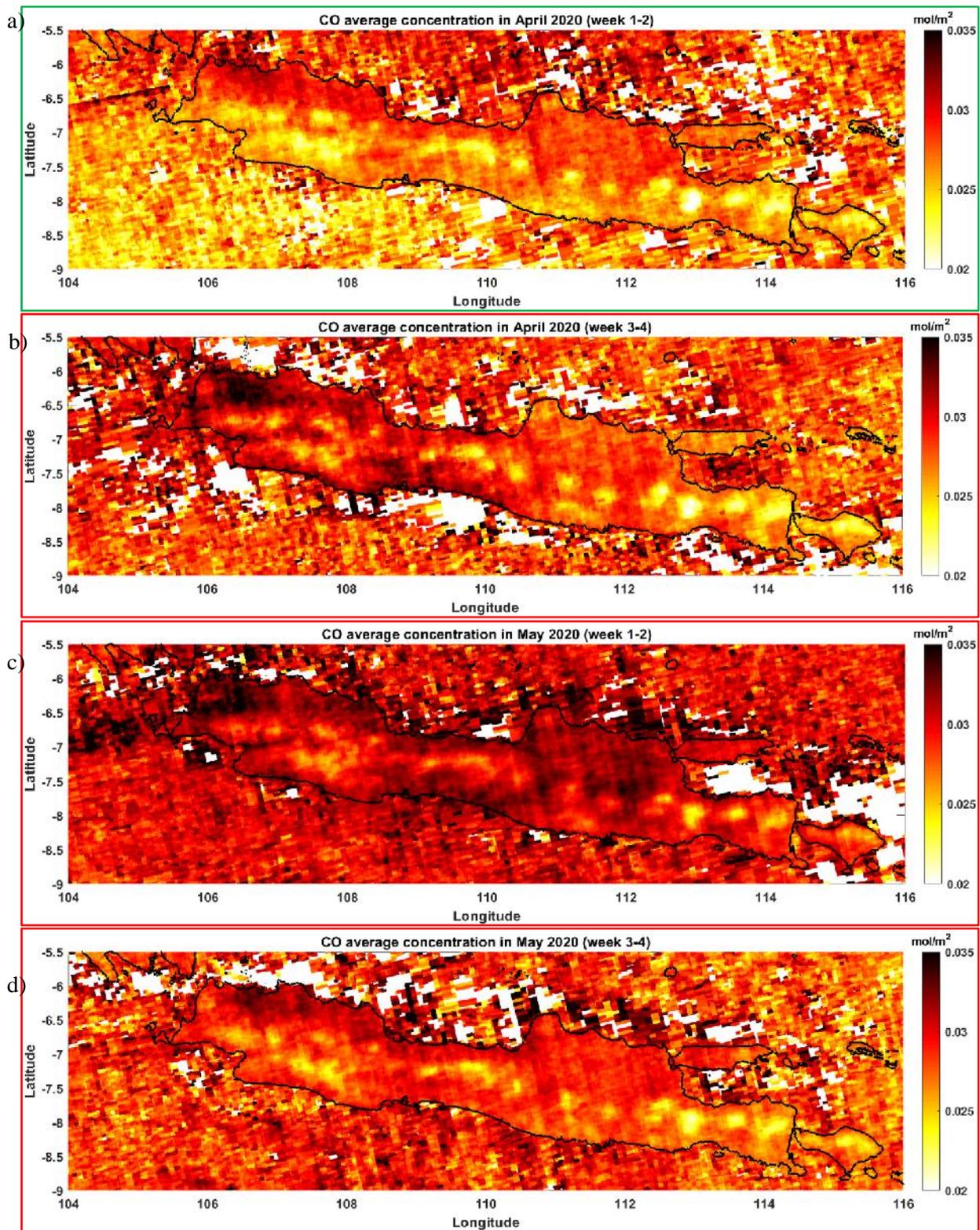
Jakarta, and surrounding areas. NO₂ concentrations tended to increase between mid and late May, found in the southern part of Banten, West Java, and East Java (Surabaya).

The concentration of CO obtained from satellites during the PSBB phase can be seen in Figure 4. The concentration above the island of Java ranged from 0.02 to 0.035 mol/m². In early to mid-April, lower CO concentrations were found along the southern part of of Java. The pattern is also different from the NO₂ pattern. When NO₂ decreased, CO did the opposite. The increase occurred in earlier PSBB on April and early May. However, CO average decreased in the 3rd-4th week of May. In the initial phase of PSBB (week 3-4 April), CO was concentrated in the provinces of DKI Jakarta, Banten, and Central Java with values above 0.03 mol/m². In the following month, CO spread more into East Java, and in the previous area, the value became higher. CO was also found in marine areas, in contrast to NO₂ which is generally concentrated in land areas.



Gambar 3. Konsentrasi NO₂ rata-rata di Pulau Jawa pada a) kondisi pra-PSBB, b) akhir April 2020, c) awal Mei 2020, dan d) akhir Mei 2020

Figure 3. NO₂ concentration over Java Island on a) Pre-PSBB condition, b) late April 2020, c) early May 2020, and d) late May 2020



Gambar 4. Konsentrasi CO rata-rata di Pulau Jawa pada a) kondisi pra-PSBB, b) akhir April 2020, c) awal Mei 2020, dan d) akhir Mei 2020

Figure 4. CO concentration over Java Island on a) Pre-PSBB condition, b) late April 2020, c) early May 2020, and d) late May 2020

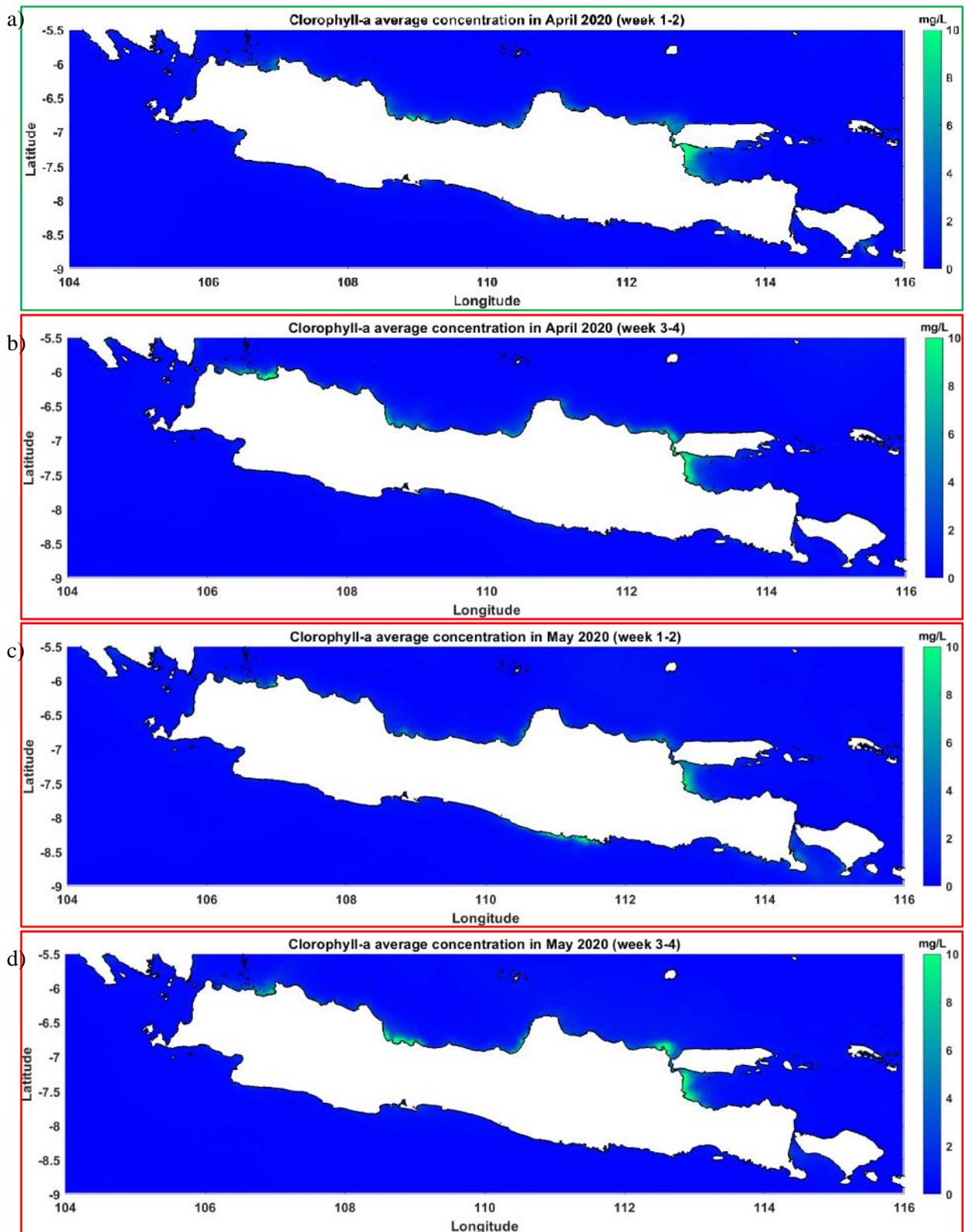
The daily average of chlorophyll-a concentration from multi-satellite provided by CMEMS is shown in Figure 5. The significant high level of chlorophyll-a concentration indicates by green color while less chlorophyll-a is blue.

The higher chlorophyll-a concentration were found on certain coasts in Java Island, particularly in Jakarta, Surabaya (East Java), Cirebon (east from Tegal), Semarang (north part of Central Java), and near Yogyakarta Province. The average

value was less than 4 mg/L on the rest area, thus hard to be seen. In this study, the dynamical change of high chlorophyll-a concentration (more than 6 mg/L) was observed. In Jakarta Bay (northern part of Jakarta Province), high concentration was found in the earlier phase of PSBB and reduced in the following month. However, the value of chlorophyll-a concentration in PSBB was still larger than in pre-PSBB. In Surabaya, the chlorophyll-a concentrations were relatively high both before and after PSBB enactment. Meanwhile, the value kept increasing on the northern coast of Central Java. Chlorophyll-a concentration was only considerably high in Yogyakarta only on the first and second week of May.

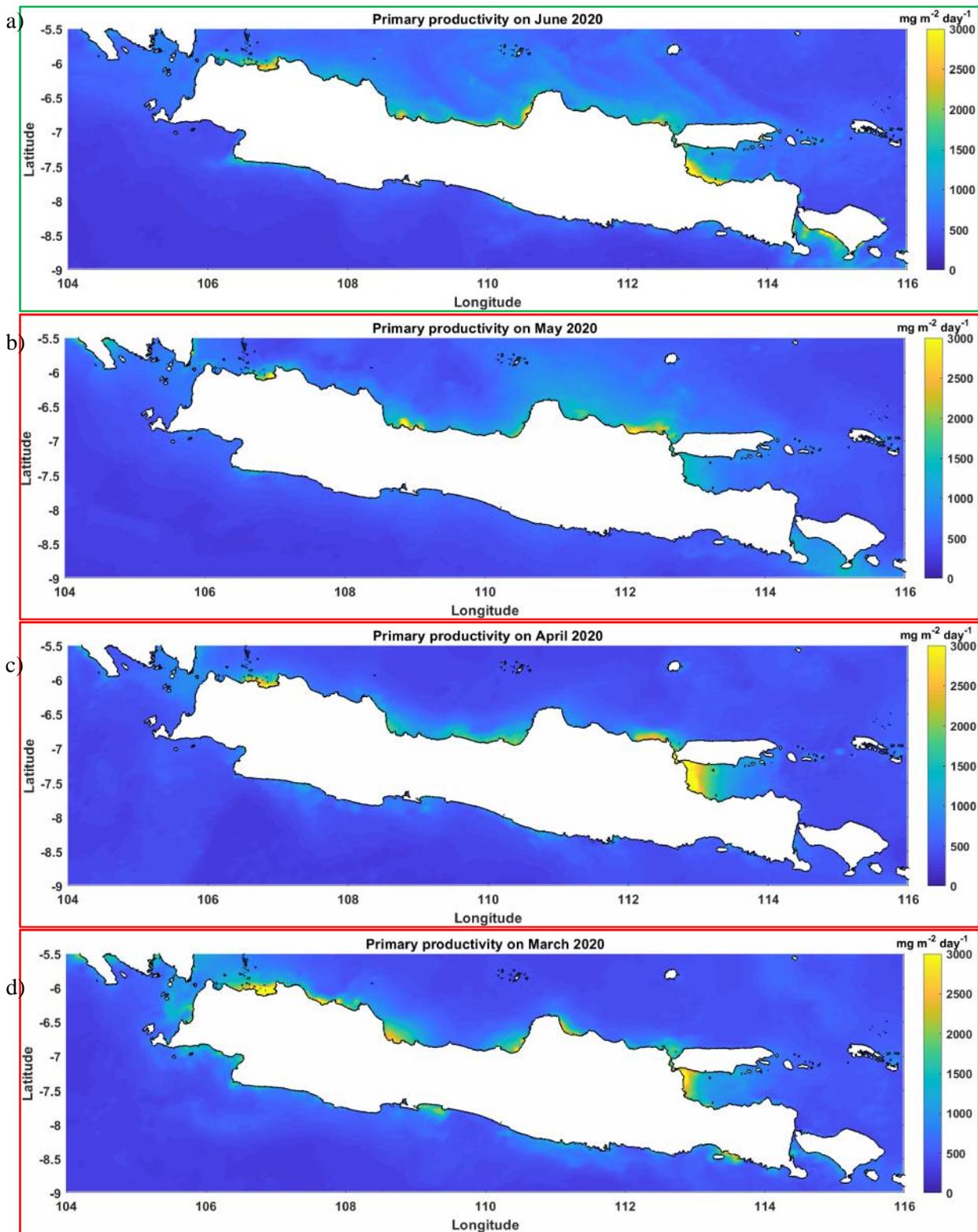
The monthly average of primary productivities were derived and can be observed in Figure 6. However, since the data was not provided in daily data, it is difficult to distinguish the transition phase in April. Thus, for the primary

productivity parameter, it was assumed that March is categorized as pre-PSBB phase. Primary productivity values showed the water sufficient to produce biomass for phytoplankton, including oxygen production produced from photosynthesis, which can be affected by chlorophyll-a and nutrients (Hariyadi et al., 2010). Higher primary productivity is indicated by more yellowish than its surrounding. It can be observed several locations that have high productivity, particularly on northern coast of Java Island. Jakarta, Surabaya, and northern coast of Central Java are some of noticeable locations. In March, higher primary productivity was found in Jakarta and Surabaya, with a value above 2500 mg/m² per day. The productivity in several locations decreased in April, except in Surabaya, which spread more in Surabaya's northern and southern regions. The area with high productivity gradually decreased until May; however, it increased back in June.



Gambar 5. Konsentrasi klorofil-a rata-rata di Pulau Jawa pada a) kondisi pra-PSBB, b) akhir April 2020, c) awal Mei 2020, dan d) akhir Mei 2020

Figure 5. Chlorophyll-a average concentration over Java Island on a) Pre-PSBB condition, b) late April 2020, c) early May 2020, and d) late May 2020



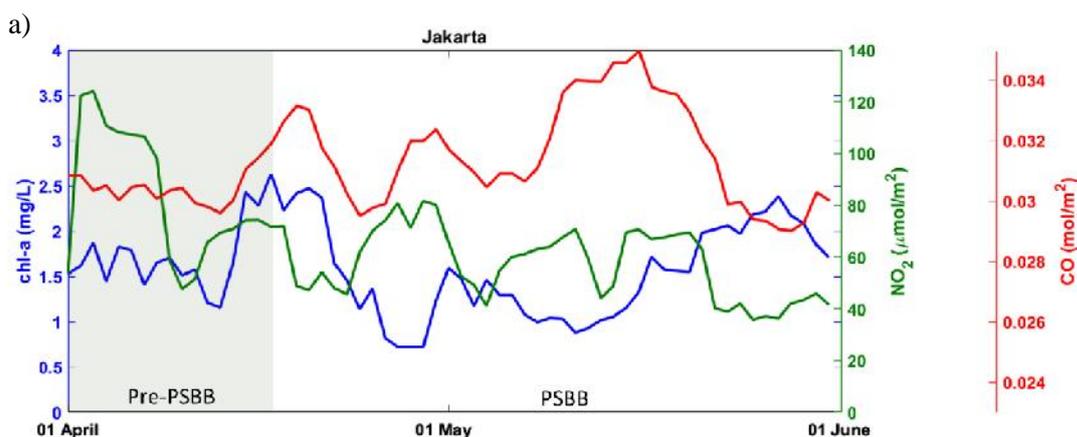
Gambar 6. Produktivitas primer rata-rata di Pulau Jawa pada a) kondisi pra-PSBB, b) akhir April 2020, c) awal Mei 2020, dan d) akhir Mei 2020
Figure 6. Average primary productivity over Java Island on a) Pre-PSBB condition, b) late April 2020, c) early May 2020, and d) late May 2020

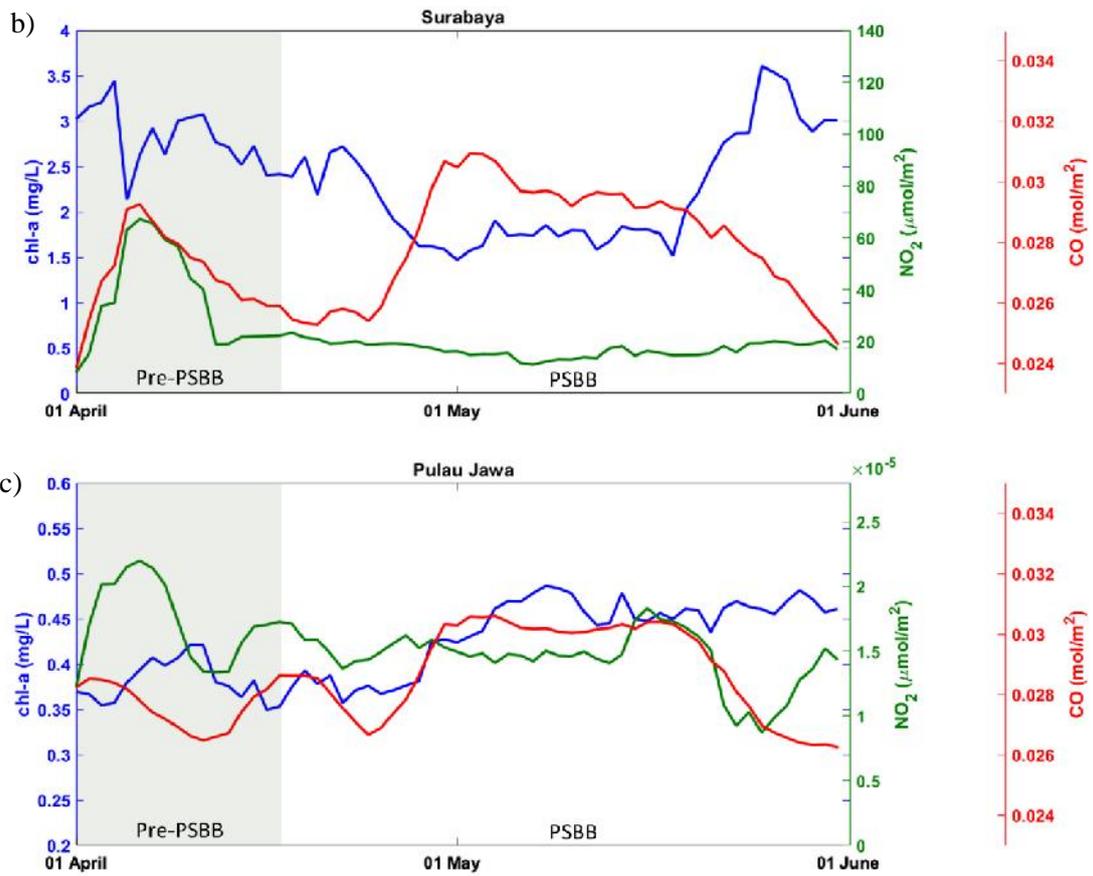
Based on previous results, Jakarta and Surabaya have become the most noticeable region in atmosphere and ocean parameters changing. Therefore, both regions were observed detailly to see the dynamical change towards time (Figure 7). Also, the chlorophyll-a concentrations had been compared to previous three years average in the same month (Figure 8). In general, each parameter tended to fluctuate during PSBB phase.

In Jakarta, NO_2 concentration decreased when PSBB was implemented, although fluctuations still occurred. NO_2 concentration average could reach $120 \mu\text{mol}/\text{m}^2$ and gradually decreased over time. However, at a certain time, its value rised than before. On the other hand, CO concentration increased in the PSBB phase. CO is relatively stable in the initial phase and increased, fluctuating up to $0.034 \text{ mol}/\text{m}^2$. The chlorophyll-a concentration tended to change at certain times following the fluctuating pattern of NO_2 and CO. When NO_2 and CO increased at the end of April, the chlorophyll-a values reached their lowest point before risen again. However, if both NO_2 and CO decreased, the chlorophyll-a concentration in Jakarta coast was increasing, which can be seen at the end of May. The condition in Jakarta is complicated, but in Surabaya, the condition is clearer to be seen. The transition of PSBB started at the end of April. It was found that when CO increases sharply, chlorophyll-a would decrease. NO_2 concentrations were relatively stable in Surabaya, other than at the beginning, the peak value can be seen along with CO concentration. In

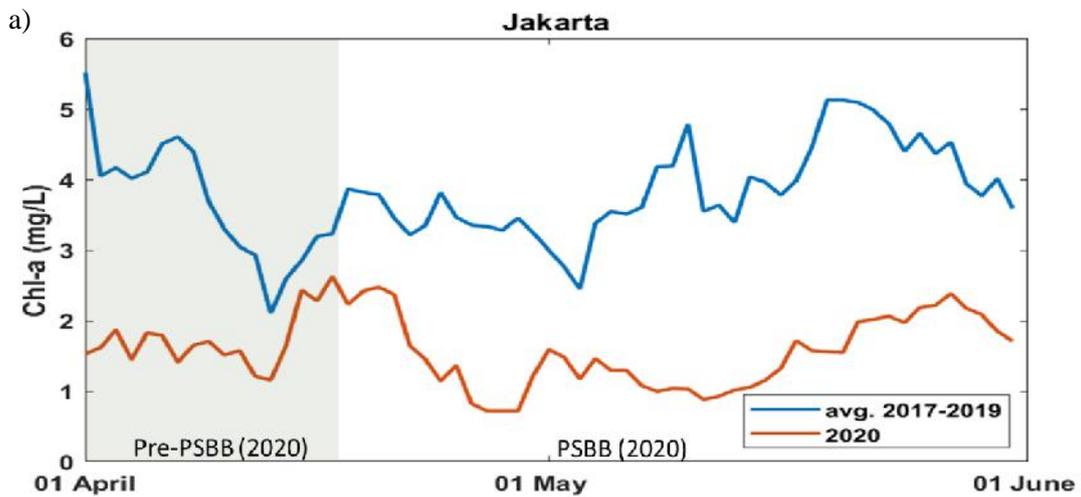
this region, chlorophyll-a concentrations decreased during PSBB, while NO_2 concentrations were relatively stable with a value of about $20 \text{ mol}/\text{m}^2$. Chlorophyll-a concentration slightly increased during the PSBB transition period. However, it was reduced to a slight increase in late May. In both Jakarta and Surabaya, chlorophyll-a concentrations increased again at the end of May.

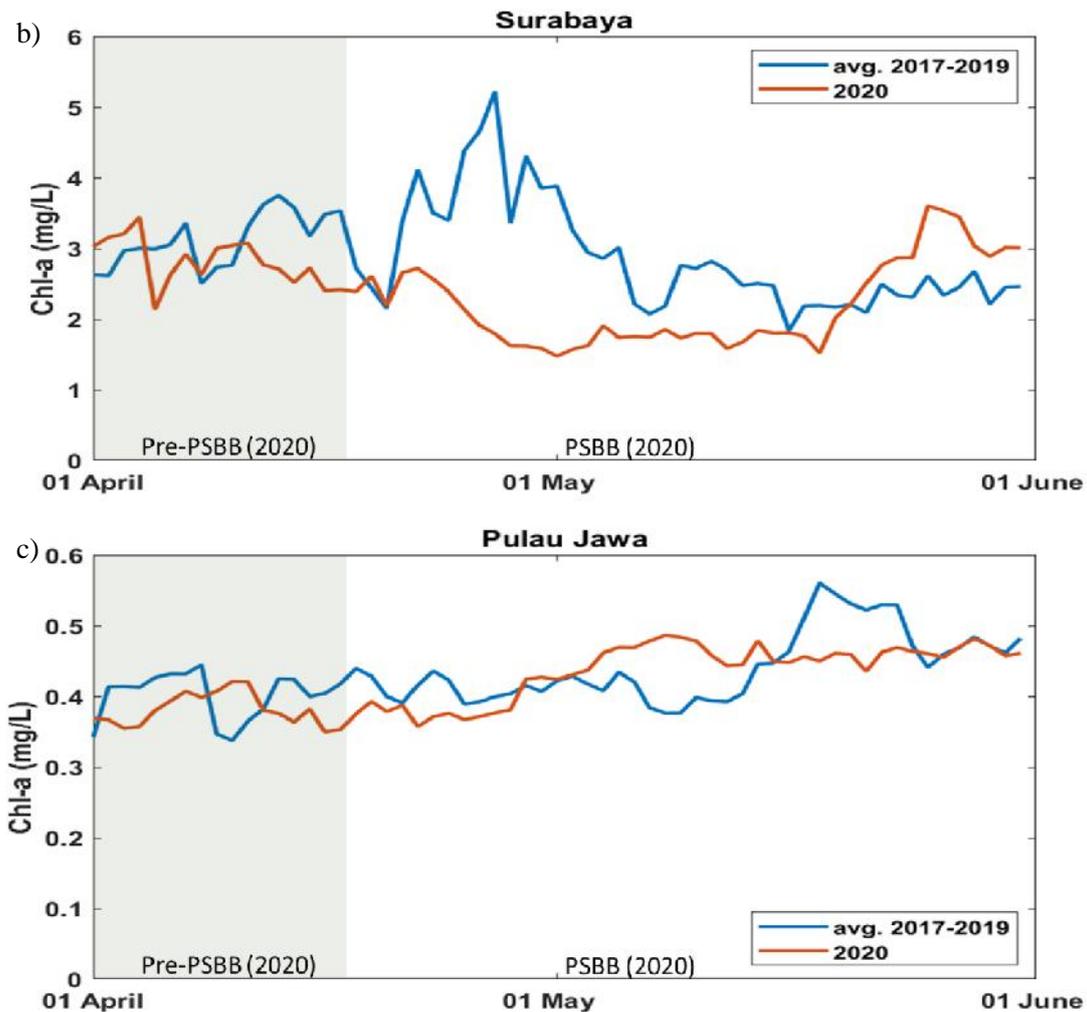
Chlorophyll-a concentration April and May 2020 were lower than the past three years (2017-2019), particularly in Jakarta and Surabaya. In Jakarta, the average of chlorophyll-a concentration in 2020 was $2 \text{ mg}/\text{L}$ lower in 2020 than in previous years. Chlorophyll-a concentration increased during the transition of pre-PSBB to PSBB phase, then decreased again before it turned up at the end of May. In contrast, in recent years, chlorophyll-a decreased before started to increase from early May. A similar pattern was seen in Surabaya where chlorophyll-a decreased during the PSBB phase transition and increased again towards the beginning of June. However, in recent years, the concentration increased in late April and then decreased. The changing pattern for each region was different from the pattern of the whole island of Java. In addition, both results showed a slightly increasing trend from early April to late May. It should be noted that the value was smaller because the entire area had been averaged, including certain areas with a small amount of chlorophyll-a concentrations.





Gambar 7. Perbandingan konsentrasi NO₂, CO, dan klorofil-a di a) Jakarta, b) Surabaya, dan c) keseluruhan Pulau Jawa
 Figure 7. NO₂, CO, and Chlorophyll-a concentration comparison in a) Jakarta, b) Surabaya, and c) whole Java Island





Gambar 8. Perbandingan konsentrasi klorofil-a pada tahun 2020 dan rata-rata tahun 2017-2019 di a) Jakarta, b) Surabaya, dan c) keseluruhan Pulau Jawa.

Figure 8. Chlorophyll-a concentration comparison between 2020 and average of 2017-2019 in a) Jakarta, b) Surabaya, and c) whole Java Island.

Discussion

Ocean and atmospheric conditions can be monitored by satellite imagery; however, the specific relation of each component's contribution should be traced further. Other components captured by satellite imagery, i.e., CHCO, CH₄, SO₂, and aerosol, might be affected during the PSBB enactment. However, the impact on the environment is not considered in this study. The concentration of NO₂ and CO in the atmosphere is fluctuating; however, there is a decreasing trend in the pandemic compare to the previous years on a global scale (AlShehhi & Abdul Samad, 2021). Atmospheric NO₂ in West Java, Banten, and Jakarta decreased compared to 2019 due to a slowdown in emissions transport and industry as the primary NO₂ sources (Myllyvirta et al., 2020). In this study, the concentration change is the main concern without considering each component's standard quality.

It is necessary to involve social aspect to comprehend the process and the result of PSBB enactment in the Java Island region. The application periode in Java Island was different in each area; so that the condition of marine parameters was difficult to be tracked. It is preferable to monitor marine characteristics in local areas, such as Jakarta and Surabaya, rather than the entire coast of the island of Java. Moreover, the conditions in reality were not as trivial as planned. In addition, a decrease in NO₂ concentration occurred 1-2 days after the implementation of the PSBB. However, an increasing phenomenon occurs when people were still carrying out their activities, especially on holidays and weekends (Anggraini et al., 2020). Moreover, in the third week of May, the mass of humans and transportation occurred since there was a Muslim holiday. The majority and the culture of gathering with their family across the city or region could not be avoidable.

Approaching June, it seems that the implementation of the PSBB was not effective because people would return to their cities and tended to work to earn a living rather than just staying at home.

Others also study the variation of atmosphere and ocean component concentration in many places during the pandemic. It was found a decrease in atmospheric component concentration in India (Panda et al., 2021), Argentina (Bolaño-Ortiz et al., 2020), China (Lian et al., 2020; Zhang et al., 2020), and more which led to better air quality during their lockdown period. The concentration likely to reduce 60% or more depends on the component. However, the atmosphere concentration recovered after the lockdown period ended. In terms of ocean parameters, Cherif et al. (2020) found a decrease in sea surface temperature, air temperature, and *Escherichia coli* (bacteria) in their observation area due to a decreasing industrial activity surrounding the river estuary in the year 2020 (lockdown) compare to 2019. Yunus et al. (2020) found 10.3% – 36.4% fewer suspended particulate matter in Venamband lake, India. The pollution from industries and tourism had a severe impact on water quality, meanwhile non-industrial pollution remained during lockdown period.

The variation of atmosphere and ocean parameters in Java Island was probably difficult to see compared to other studies taken in other cities worldwide. PSBB is a bit different; the regulation is not strict as other cities on lockdown strategies. Moreover, the size of Java Island and people's behavior made the PSBB hit below the target. Therefore, the changing in each observed component (Figure 6-8) was unclear spatially. However, the reduction of chlorophyll-a concentration was distinguishable when the concentration was observed in the pandemic compared to the previous year (Figure 8). This result is in line with chlorophyll-a study in Jakarta by Adwibowo (2020). They concluded that the dynamic of anthropogenic activities was responsible and associated with the water quality and nutrient contents as indicated by chlorophyll-a levels in the coastal. The analysis showed that reductions of levels and areas of chlorophyll-a concentration are a function of social distancing and activity restrictions.

Primary productivity was commonly found higher in coastal areas than offshore areas since important ecosystem was near the coastal area, such as coral, seagrass, and mangrove supplies more nutrients (Nuzapril et al., 2017). In this study, several locations with higher primary productivity were mainly found in northern part of

Java Island. In this area, mangrove and seagrass were more dominant than in the southern part of Java Island. Moreover, numerous rivers end in the northern part of Java Island. Many nutrients reached the sea and were transported to the nearby coast area by current and wave. Although many rivers also end in the southern part of Java, the influence from the ocean was greater than discharge, which could influence further in the river canal. When the nutrient reached the southern part of Java, it might be carried far from the sources/estuaries or dispersed quickly, so the satellite only captured it as a low chlorophyll-a concentration area. However, several areas in the southern part of Java sometimes had high chlorophyll-a concentration due to many nutrients, such as from flood events or sources close to the main city (high human and industrial activities). The amount of nutrients on each river was different, thus made several locations have higher or lower chlorophyll-a than other locations, even in pandemic situations. Therefore, the activity inland and surrounding the specific area should be considered more.

Coastal areas with shallow depth with sufficient sunlight and nutrients from land also have high primary productivity (Asriyana & Yuliana, 2012). The dynamic factor such as human activity, industrial sector, and transportation in numerous locations could affect the atmosphere and ocean sector. Nutrients from land, commonly from housing, farming, and industry, are brought by river to the sea. Agricultural activity and industry have a significant role since the sources' waste containing nutrients and chemical compounds can enhance chlorophyll-a's concentration on the coast. Besides that, the source of chlorophyll-a productivity may lie in chemical compound transfer between ocean and atmosphere. Air pollutants, such as NO₂, SO₂, CO, and atmospheric dust, can be carried away after turning into chemical compounds in liquid form, for example, acid rain. Nutrients then spread in the coastal around the estuary or even further when the tides, wind, waves, and currents are considered. Air-sea interaction can occur through wave breaking. Nitrate, phosphate, silicate, and other nutrients carried by a river into the sea will be beneficial for phytoplankton to do photosynthesis. Therefore, variations in the concentration of this nutrient may affect chlorophyll-a concentration and primary productivity.

There is a positive correlation between chlorophyll-a and primary productivity (Gong et al., 2000; Mantyla et al., 2008). However, the relation should be supported with another ocean

parameter, such as sea surface temperature and salinity. On the otherhand, phytoplankton photosynthesis which relates to primary productivity is mainly influenced by light, nutrients, and species composition (Smith, 1980; Eppley et al., 1985). Temperature and salinity show a positive relation with primary production and particulate organic carbon. Primary productivity has a negative relationship with nitrate and phosphate. Moreover, primary production reaches its peak when nitrate-nitrogen and phosphate-phosphorus have lower concentrations (Gowda et al., 2002). If the primary production is parallel with the chlorophyll-a, it is a coincidence that high chlorophyll-a concentration is high during low NO₂ in Jakarta (Figure 7a). However, this study only involved nitrogen and carbon as air pollutants, not in liquid form (not sink in the sea yet). Although the CO also shows a negative relation pattern compared to chlorophyll-a in Jakarta and Surabaya (Figure 7a and 7b), the relation is still uncertain. Therefore, an advanced investigation is necessary in terms of the air-sea interaction mechanism on a microscale to see the relation between ocean chlorophyll-a and NO₂ and CO concentration.

Seasonal factors are interesting to observe because parts of Indonesia are most likely affected by monsoon winds. In this season, the wind blows relatively to the southeast. The distribution of NO₂ becomes reasonable if the source mainly from Jakarta and its surrounding or northern part of Banten province spreading to the east, as captured in Figure 3. Global-scale phenomena, such as El-Nino Southern Oscillation (ENSO), dipole mode index (DMI), can affect the migration of each observed component. The ENSO index was relatively stable in March-April-May (MAM) 2020 period. The extreme weather event occurred commonly if the index is on the peak (highest or lowest).

Conclusion

Multi-satellite image data can be used to monitor atmospheric and marine parameters on the island of Java, Indonesia, as long as the PSBB policy was adopted. Atmospheric NO₂ concentration in the atmosphere decreased in earlier phase of PSBB, especially in the 3-4 week of April and the week of 1-2 May. On the other hand, CO concentrations increased and began to decline at the end of May due to mass movement of people or transportation during religious holidays/holidays. These two atmospheric parameters most likely affect the increase/decrease in the value of chlorophyll-a because its concentration can affect

nutrients on the coast, but this needs to be investigated further. There were fluctuations in marine chlorophyll-a concentration and primary productivity in the Java Sea. The decrease in chlorophyll-a concentrations shown in Jakarta and Surabaya in April-May was 48% and 27% lower than the previous three-years average due to lower human activities as a capital city. Primary productivity tended to be more concentrated along the northern coast of Java and declined in May. As of biological data, in-situ observations, and water quality data were absent in the study, however the differences in daily chlorophyll-a, NO₂, and CO concentrations under PSBB conditions can be distinguished.

Acknowledgement

This research was a part of the project titled "Marine Science & Technology Cooperation between Korea and Indonesia (20180319)" and "Ocean and Coastal Basic Survey and Capacity Enhancement in Cirebon, Indonesia (G51910)" funded by the Ministry of Oceans and Fisheries, Korea. This study acknowledges Copernicus Marine Service Team (CMEMS) that provides ocean color data (<https://marine.copernicus.eu/>) and Copernicus European Space Agency (ESA) that provides TROPOMI Sentinel 5P (<https://scihub.copernicus.eu/>) which both can be accessed and retrieved by public.

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