RESEARCH PAPER

SEASONAL MONITORING OF CHLOROPHYLL-A WITH LANDSAT 8 OLI IN THE MADURA STRAIT, PASURUAN, EAST JAVA, INDONESIA

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ABSTRACT. Chlorophyll-a (Chl-a) is a type of pigment is most common and predominant in all oxygen-evolving photosynthetic organisms such as higher plants, red and green algae. The concentrations of high chlorophyll-a (Chl-a) in coastal waters tend to be lower offshore due to land through river water runoff. The Madura Strait is one of the Indonesian basins that is widely used for fisheries activity, which directly impacts and puts quite high pressure on the aquatic resources. In addition, the development of urban areas and changes of land use in the hinterland areas of East Java Province due to increasing population are also intensive. The objectives of this research were: (1) to map the distribution of chlorophyll-a, its concentration and dynamics in the Madura Strait near the Pasuruan coastal area using remote sensing for both dry and rainy seasons, (2) figure out the influence of rivers or other oceanographic factors that may occur, and (3) calculate the accuracy of the estimation compared to the field data. The Landsat 8 OLI imagery was used to determine the concentration of Chl-a and analyze its seasonal spatial distribution pattern. The results show that (1) spatial distribution of chlorophyll-a (Chl-a), its concentration and dynamics in the Madura Strait waters near the Pasuruan coastal area varies between dry and rainy months or seasons, (2) input from rivers, waves, tidal level, and eddy circulation constitute the oceanographic parameters that influence the spatial distribution pattern of chlorophyll-a (Chl-a) in the Madura Strait waters near the Pasuruan coastal area, and (3) validation of the estimated Chl-a concentrations from Landsat 8 OLI using field data has shown RMSE value of 0.49.

KEYWORDS: Chlorophyll-a, Landsat 8, remote sensing, spatial distribution, Madura

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INTRODUCTION

Chlorophyll-a (Chl-a) is a type of pigment is most common and predominant in all oxygen-evolving photosynthetic organisms such as higher plants, red and green algae. It is best at absorbing wavelength between 400-450 nm and 650-700 nm range of the electromagnetic spectrum (Ibrahim 2016). Chlorophyll-a is also present in aquatic organisms such as phytoplankton and algae. It enables them to use energy from the sunlight to convert carbon dioxide into complex organic molecules, such as sugar or protein (Suther & Rissik 2009). Due to the chlorophyll-a property of phytoplankton that allows them to absorb certain wavelengths of the electromagnetic spectrum, their concentration in water can be estimated using remote sensing data from a satellite that is equipped with a sensor system sensitive to these particular wavelengths. The concentration as identified and estimated from remote sensing can be used as a proxy that reflects the amount of phytoplankton. Moreover, estimates of the chlorophyll-a concentrations can be used to estimate the primary productivity of waters.

Meanwhile, the concentrations of chlorophyll-a (Chl-a) in coastal waters tend to be lower offshore due to the land through river water runoff. However, in several places in the sea, chlorophyll-a concentrations were still found entirely high. This is caused by the presence of a water mass circulation which allows trapping of some nutrients from other places (Paramitha et al. 2014). As a result, monitoring of the dynamics, distribution add and concentration of chlorophyll-a through satellite imagery can be used in coastal zone management and aquatic resource management as well.

The Madura Strait is one of the Indonesian basins that widely used for fisheries activity, which directly impacts and puts quite high pressure on the aquatic resources. In addition, in the hinterland areas of East Java Province, the development of urban areas and changes of land use due to increasing population are also intensive. Because of that, it is suspected that there are many pollutants and land erosion products that are carried out by the rivers into the Madura Strait. There are many rivers that flow into the Madura Strait such as the Brantas River (including Porong and Kali Mas) in Sidoarjo Regency, Kali Jagir (Wonokromo) in Surabaya City, Gembong, Rejoso, Petung, and Porangan Rivers in Pasuruan etc. The Sidoarjo-Surabaya City rivers are part of the Brantas Watershed which begins from Mount Arjuno – Welirang. Meanwhile, the Rejoso River and many other rivers in Pasuruan are part of the Welang-Rejoso Watershed, which starts from the Bromo – Tengger mountains. As a consequence, those rivers that flow to the Madura Strait from Sidoarjo, Surabaya add or Pasuruan already pass through different landscapes and are affected by various human activities as they flow miles away from their wellsprings. On the other hand, the Madura Strait is also connected to the Java Sea and the Bali Strait, which makes it very complex in terms of fisheries and oceanography. From both these perspectives, it is important to study chlorophyll-a concentration, which reflects phytoplankton and their dynamics in the Madura Strait.

In general, objectives of this research were: (1) to map the distribution of chlorophyll-a, its concentration and dynamic in the Madura Strait near the Pasuruan coastal area using remote sensing for both dry and rainy seasons, (2) figure out the influence of rivers or other oceanographic parameters that may occur, and (3) calculate the accuracy of the estimation compared to the field data.

The research used spectral indices obtained from satellite remote sensing imagery for mapping of Chl-a in the Madura Strait waters. We used an equation developed by Bhirawa and Djaelani (2015), which only requires the values of reflectance for Band 4 and Band 5 of Landsat 8 OLI rather than the algorithm used by Watanabe et al. (2018) and Yadav et al. (2019). Results from the equation were validated with in situ data to determine the accuracy of the Chl-a estimation from the Landsat 8 OLI data.

MATERIALS AND METHODS

The study area was located in the Madura Strait waters, to the north of Pasuruan City and Pasuruan District, East Java, Indonesia (Fig. 1). As the main data source, we used the Landsat 8 OLI path: 118 row: 65 from May 2019 to September 2020 (from http://earthexplorer.usgs.gov). Moreover, to verify the estimation from the Landsat imagery analysis, field data on chlorophyll-a (Chl-a) were obtained from three sampling locations in (1) the Nguling, (2) Lekok, and (3) near Kraton coastal area with JFE Model AAQ 1183s-IP, which is a water quality profiler or a device to measure water quality. The field measurements with the water quality profiler were conducted on 16 August 2020, on the same day and nearly at the same time with the scene center of the Landsat 8 OLI image as it was crossing the research area at 9:35 am. With one water quality profiler available and a small boat to reach the area, we were only able to measure at 3 sampling locations. Besides that, we also obtained the data on currents direction and rainfall data from BMKG (The Indonesian Meteorological, Climatological and Geophysical Agency) along with the data on rivers and streams from the RBI Map/ topographic map of BIG (The Indonesian Bureau of Geospatial Information).

Within the Landsat 8 OLI image processing, we determined Top of Atmosphere (TOA) reflectance from the planetary spectral reflectance with correction for solar angle using an equation expressed as:

$$\rho\lambda' = M\rho * Qcal + A\rho \quad (1)$$

$$\rho\lambda = (\rho\lambda'/\cos(\theta SZ)) = (\rho\lambda'/\sin(\theta SE)) \quad (2)$$

where: $\rho\lambda'$ is TOA planetary spectral reflectance (unitless), $M\rho$ is reflectance multiplicative scaling factor for the band (taken from the metadata), $A\rho$ is reflectance additive scaling factor for the band (also taken from the metadata) and Qcal is Level 1pixel value in Digital Number (DN). Moreover, $\rho\lambda$ is TOA planetary spectral reflectance with correction for solar angle (unitless), θSE is local sun elevation angle, the scene center sun elevation angle in degrees is provided in the metadata, and θSZ is local solar zenith angle (USGS 2019). Chl-a was estimated from the Landsat 8 OLI images using the equation adapted from Bhirawa and Djaelani (2015), which was developed to observe water quality using Landsat 7 ETM. The equation is as follow:

$$\text{Chl a} = 0.9889\ (ETM3/ETM4) - 0.3619$$
$$\rightarrow \text{Chl a} = 0.9889\ (Rs4/Rs5) - 0.3619 \quad (3)$$

where: ETM3 and ETM4 is the TOA reflectance of Band 3 and Band 4 of Landsat 7, respectively. Meanwhile, Rs 4 and Rs5 is the TOA reflectance of Band 4 and Band 5 of Landsat 8 OLI. ETM3 and ETM4 are equal to Rs 4 and 5 in Landsat 8 OLI. The image processing was conducted with Quantum GIS 3.10 Coruna on Windows 10 - 64 bit.

Validation of the Chl-a estimation from the Landsat 8 OLI data was performed using RMSE (Root Mean Square Error) with the equation as follows:

Where $\hat{y}i$, $\hat{y}n$ are predicted values, yi, yn are observed

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \quad (4)$$

values and n is the number of observations.

RESULTS

The concentrations of Chl-a, obtained from the analysis of the Landsat 8 OLI imagery path: 118 row: 65 acquired from May 2019 to September 2020 using equation (3), are presented in Table 1 and Table 2. From the two tables, it can be clearly observed observed that Chl-a concentration in each sampling location was dynamic and was characterized by a certain pattern. The concentration of Chl-a was at the lowest level during rainy months such as November, December, January. Meanwhile, during dry months such as June, July, and August, the Chl-a concentration was higher than during the rainy months. The detailed dynamics of Chl-a concentration are presented in Figure 2.

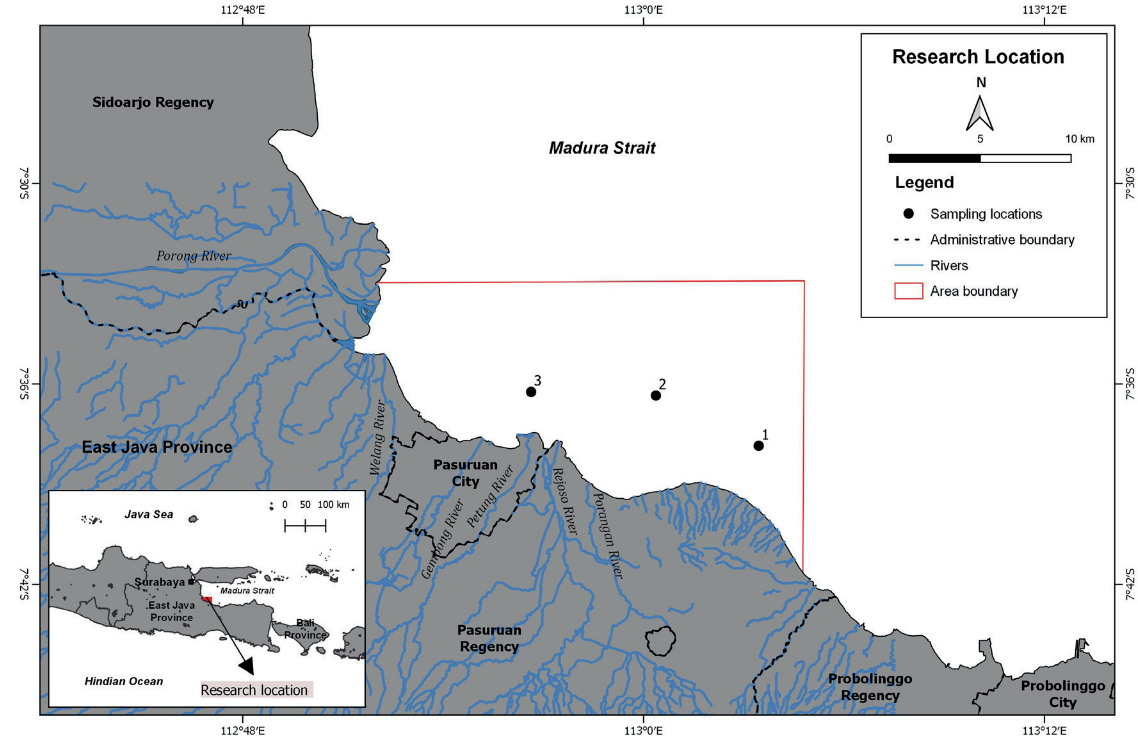

Fig. 1. Research location in the Madura Strait, Pasuruan

May 2019 – September 2020Furthermore, according to Figure 2, Nguling was characterized by the highest average Chl-a concentration compared to two other locations, while Lekok had the lowest average Chl-a concentration among others. From a spatial perspective, during the period from May 2019 to September 2020, the distribution of Chl-a was also dynamic as represented in Figure 3.

In several locations the concentration of Chl-a was high (represented by red color), in other locations it was low (represented by green color). For example, in the Madura Strait waters close to the Porong River mouth, the average concentrations were higher for the entire period except October 2019 and May 2020. From a spatial point of view, the existing rivers that end up in the Pasuruan coastal area where it directly connects to the Madura Strait influenced the concentration of Chl-a respectively as they transport nutrients from the hinterland to the Madura Straits. Unfortunately, Landsat 8 imagery for February 2020 could not be obtained and analyzed because the high clouds cover.

DISCUSSION

Dynamics and spatial distribution patterns of Chl-a

According to Figure 4, the Madura Straits waters near the Pasuruan coastal area have 4 seasonal patterns of Chl-a distribution. The first distribution pattern is represented by the figures where a high concentration of Chl-a is observed near the Porong River mouth and spreads to the area around Nguling waters (sampling location 1). An example of this distribution pattern can be seen on 26 May 2019, which is shown in Figure 4 (a), as well as on 15 September 2019 and 16 August 2020. The second distribution pattern was observed on 01 October 2019 and is given in Figure 4 (b). It is marked by an almost uniform Chl-a concentration in the waters of the Madura Strait close to the Pasuruan coastal area. Compared to the first distribution pattern of the Chl-a concentration, the second distribution pattern shows almost a reverse situation.

Table 1. Chlorophyll-a concentration in each sampling location from May 2019 to December 2019 according to Landsat 8 OLI

Chl-a (µg/L) or mg/m³										
No	Location	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Average
1	Nguling	2.379	1.742	2.037	2.232	1.487	1.266	1.360	1.042	1.693
2	Lekok	1.643	1.640	1.652	1.407	1.272	1.045	1.233	0.998	1.361
3	Kraton	2.125	1.988	2.133	2.116	1.174	1.465	1.757	0.861	1.702

Table 2. Chlorophyll-a concentration in each sampling location from January 2020 to September 2020 according to Landsat 8 OL

Chl-a (µg/L) or mg/m³										
No	Location	Jan-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Average
1	Nguling	1.230	2.004	1.949	2.814	2.291	2.430	2.678	1.096	2.061
2	Lekok	1.319	1.328	2.015	1.692	2.137	2.302	2.359	1.079	1.779
3	Kraton	1.581	1.768	2.067	1.336	2.139	2.294	2.227	1.316	1.841

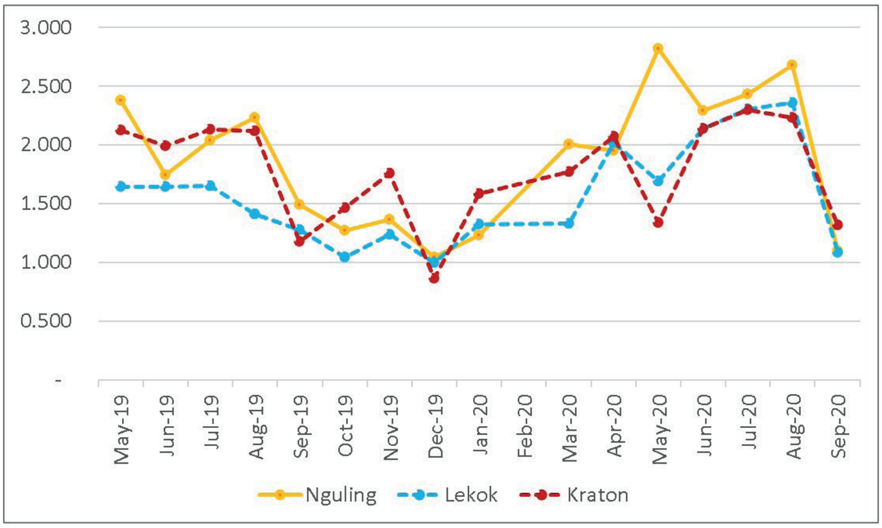

Fig. 2. Chlorophyll-a concentration (mg/m3) from Landsat 8 OLI, May 2019 – September 2020

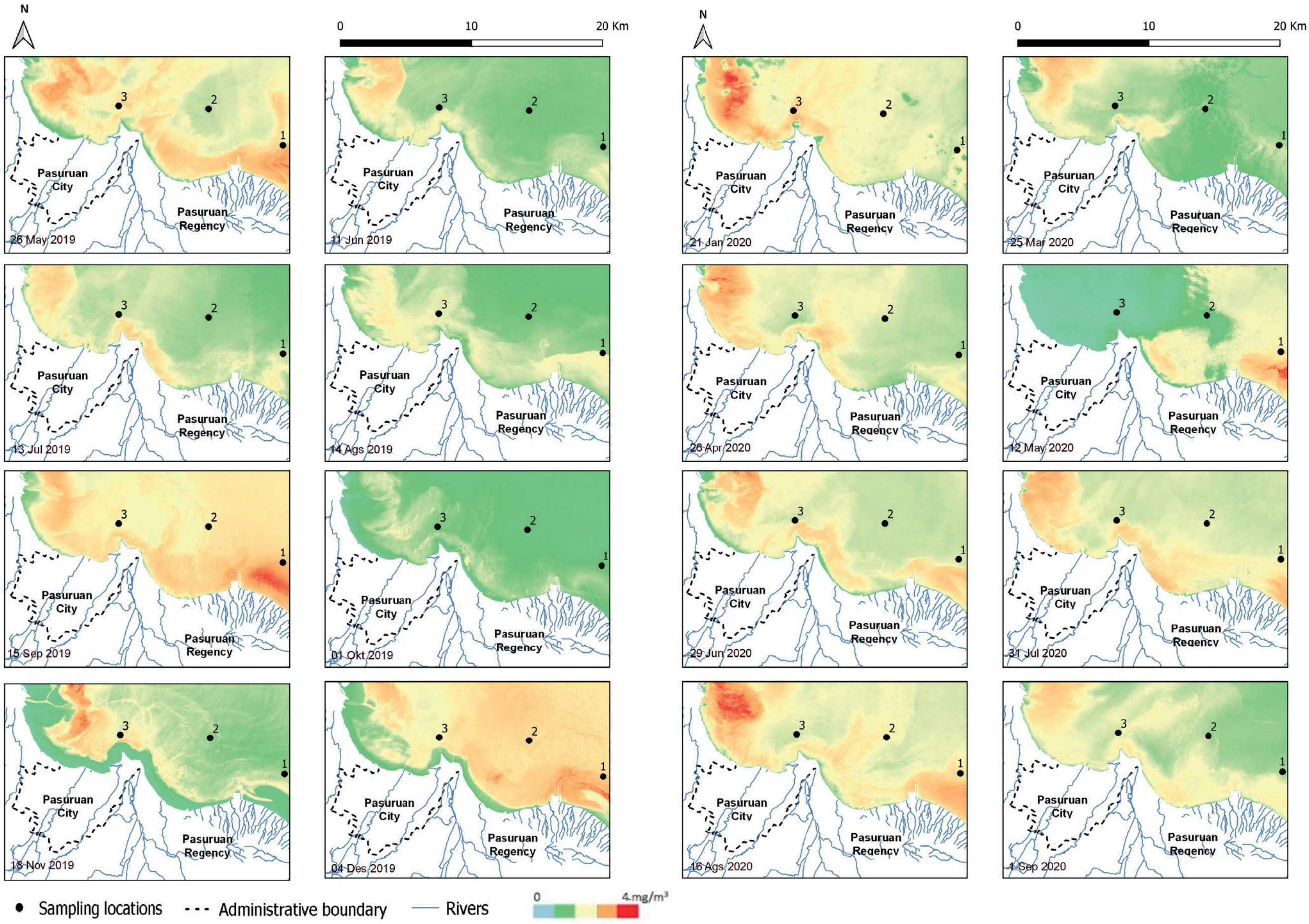

Fig. 3. Chlorophyll -a distribution from Landsat 8 OLI, May 2019 – September 2020

The third distribution pattern, presented in Figure 4 (c), is characterized by a low concentration of Chl-a in the coastal area from near the Porong River mouth to Nguling (sampling location 1). The fourth distribution pattern of Chl-a concentration was observed on 12 May 2020 and is shown in Figure 4 (d). In this case, waters from near the Porong River mouth to Kraton (sampling location 3) are characterized by a lower concentration of Chl-a compared to Nguling waters (sampling location 1). It seems that there was one center of Chl-a concentration located near Nguling (sampling location 1). We could also attribute it to the first distribution pattern (Figure 4 (a)) as it demonstrates the normal spatial distribution of Chl-a in the research location, which can be observed almost in all seasons. For further detail, see Figure 4, where all the Chl-a distribution patterns are presented sequentially.

According to Figure 3 and Figure 4, the concentration of Chl-a in the coastal area was relatively low compared to the offshore waters, which might be caused by the low tide at the moment when the Landsat 8 OLI satellite crossed and captured the waters of the research area. To give evidence of this statement, we analyzed the tide level data with the moon phase as well as the date and time of the Landsat 8 scene center acquisition as presented in Table 3. The data were obtained from the Tide Chart® application on Android® Smartphones and the Landsat 8 OLI metadata. We used the tide

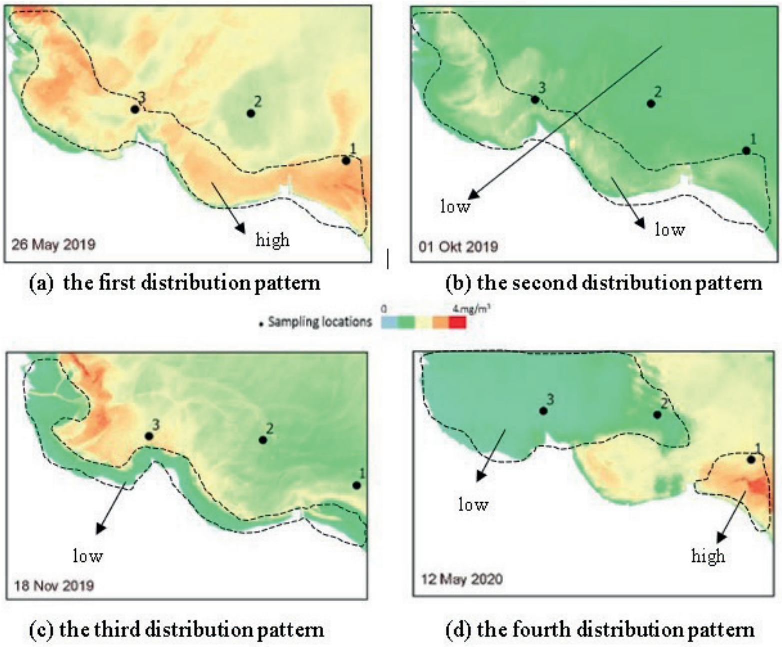

Fig. 4. Spatial distribution pattern of Chl-a concentration in the Madura Strait near Pasuruan coastal area

measurement station located in Surabaya, which was closest to the research area (See map insert in Figure 1). For example, the distribution pattern as presented in Figure 4 (c), or the third pattern, was influenced by the low tide level as seen in Table 3 row number 8. The waters near the coastal area of Pasuruan were receding when the Landsat satellites covered the area. Because of that, we can confidently state that the spatial distribution patterns of Chl-a concentration in the Madura Strait near the Pasuruan coastal area were also influenced by the tidal level. Also, the coastal area of Pasuruan includes a mangrove ecosystem, especially close to Kraton (between the Petung and Rejoso Rivers in Figure 1). In this mangrove ecosystem, tidal cycle or tidal amplitude is particularly important in determining the extent of variation of Chl-a concentration (Nion et al. 2019). Furthermore, according to H.J Ha et al. (2020), during the spring tide (when the high tide occurred at midday) Chl-a decreased during the daytime flood tide. Meanwhile, during the neap tide (when the low tide occurred at midday) Chl-a increased during the early to mid-flood tide.

Table 3. Tides and moon phase from the nearest station (Surabaya)

No	Landsat 8 OLI Date Acquired	Scene Center Time (AM)	Moon phase	Tides (m)
1	26-May-19	9:35:26	Last quarter	1.2
2	11-Jun-19	9:35:33	67% waxing	1.2
3	13-Jul-19	9:35:42	90 % waxing	1.4
4	14-Aug-19	9:35:53	99% waxing	1.6
5	15-Sep-19	9:36:02	97 % waning	1.2
7	01-Oct-19	9:36:07	13 % waxing	0.7
8	18-Nov-19	9:36:05	16 % waning	-0.1
9	04-Dec-19	9:36:04	First quarter	0.1
10	21-Jan-20	9:35:54	9 % waning	0.6
11	25-Mar-20	9:35:32	2 % waxing	1
12	26-Apr-20	9:35:16	12 % waxing	1.4
13	12-May-20	9:35:10	67 % waning	1.3
14	29-Jun-20	9:35:31	67% waxing	1.1
15	31-Jul-20	9:35:42	91 % waxing	1.4
16	16-Aug-20	9:35:47	6% waning	1.3
17	01-Sep-20	9:35:55	99% waxing	1.6

Source: Tide Chart (SeventhGear 2020)

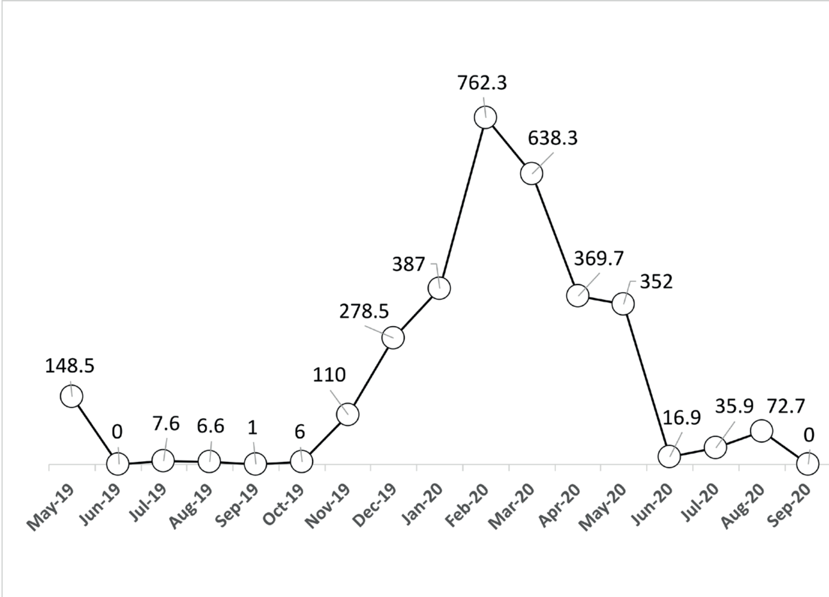

Fig. 5. Monthly total amount of rainfall (mm) recorded at Pasuruan Geophysics Station from May 2019 to September 2020 (Source: BMKG)

Low tide sometimes occurred at midday and vice versa. Research findings by Nion et al. (2019) and H.J Ha et al (2020) are relevant to the situation in the research location.

Meanwhile, according to BMKG data from May 2019 to September 2020, the highest total amount of rainfall in Pasuruan (96945-Pasuruan Geophysics Station) was in February 2020 with about 763.3 mm as represented in Figure 5. The period from June 2019 to October 2019 was characterized by the low intensity of rainfall. Although the intensity of rainfall was not very high from November 2019 to May 2020, there was rainfall occurring and it, of course, affected the discharge of river water. This condition is strengthened by Hidayah et al. (2016), where it was shown that the high chlorophyll-a concentration at the coast was due to the supply of nutrients through river runoff from the land. A similar distribution pattern of Chl-a was observed in the Madura Strait close to the Pasuruan coastal area. In the end, the dynamics, variation, and spatial distribution of Chl-a were affected by this factor too, which is in line with the research of Muhsoni et al. (2009).

We realize that in this study, monthly river discharge data was not obtained remove to precisely connecting the results from remote sensing data analysis and in situ data as it was ready in the research conducted by Siswanto et al. (2014) in the Malaka Strait. The influence of river discharge was also strengthened by the study of Masotti et al. (2018) and Otsuka et al. (2018). We also did not obtain the data on the amount of organic matter (Nitrate and Phosphate) from the river water and it is something that can be added for future research and analysis.

From a wider point of view, the Indonesia archipelago is located in the middle of the tropical region, which has two annual seasons characterized as dry and rainy. These seasons are distinguished by the different patterns of temperature as well as wind and waves direction. During dry months, the direction of waves is from east to west, including the waves in the Madura Strait. Meanwhile, in rainy months such as March, waves direction changes and becomes from west to east (locally called the western season), which is also observed in the Madura Strait. A clear example of that can be seen in the spatial distribution of Chl-a on 12 May 2020 (Figure 3). The total amount of rainfall that month was 352 mm (Figure 5) and waves were coming from the west, which resulted in the concentration and spatial distribution of Chl-a, represented by the third pattern in Figure 4 (c).

Furthermore, during the dry season when waves are directed from east to west (locally called the eastern season), we found that the concentration and spatial distribution of Chl-a corresponded to the first pattern presented in Figure 4 (a), which was observed from May 2019 to September 2019 and from June 2020 to September 2020. Unusual concentration and spatial distribution of Chl-a in the Madura Strait close to the coastal area of Pasuruan were found on 01 October 2019 when the second pattern presented in Figure 4 (b) was observed.

The spatial distribution pattern of Chl-a in the Madura Strait found in this research is also in line with the results of Semedi and Safitri (2014). It was noticed that in September, the season in the Madura Strait starts to change. This change can be observed in the data in Table 1 and Table 2 as well as Figure 2 and Figure 3 for September 2019 and 2020. The concentration of Chl-a surely went down and became less than in August 2019 and August 2020. Overall, the temporal variation pattern shows that marine waters are more turbid on rainy months than on dry months, which is in line with the research of Buditama et al. (2017). Moreover, in the broader geographic view, the distribution of Chl-a according to Taufiqurrahman and Ismail (2020) is associated with the eddy circulation in the Madura Strait. They highlighted that the deep basin under the Madura Strait creates an eddy within the water body, which appears to affect the Chl-a distribution. According to Trinugroho et al. (2019), there is also a seasonal thermal front in the Madura Strait caused by the eddy circulation, which we believe affects the distribution pattern in the waters near the Pasuruan coastal area too.

Another factor related to the dynamics and spatial distribution pattern of Chl-a that still requires further study in the research location is the thermal stratification. Thermal stratification, as mentioned by Blauw et al. (2018), also acts as one of the environmental drivers that can cause Chl-a fluctuation across different time scales and areas.

Concentration of Chl-a, tropic state and validation

Based on the Landsat 8 OLI data, Chl-a concentration in water at all the sampling locations during the period from May 2019 to September 2020, according to Novo et al. (2013), can be categorized as oligotrophic (between 1.17 – 3.24 μg/L) or < 2 μg/L (Hakanson and Blenckner 2008). Furthermore, the average concentration of Chl-a in the research area can also be categorized as medium-high to low according to Lundberg et al. (2005). The medium-high concentration of Chl-a corresponds to the range 2.2 – 3.2 μg/L and the low concentration of Chl-a is around 1.5 – 2.2 μg/L. Only Lekok, and Kraton sampling locations on 4 December 2019 and Nguling and Lekok sampling locations on 1 September 2020 were below the level of oligotrophic (ultraoligotrophic) or could be characterized by a very low concentration of Chl-a according to Lundberg et al. (2005).

As for the comparison of Chl-a derived from Landsat 8 OLI, we conducted in situ measurements on 16 August 2020 at Nguling, Lekok and Kraton. Especially in Lekok, we were lucky to arrive on time and our water quality profiler JFE Model AAQ 1183s-IP was applied close to the scene center time of Landsat 8 OLI, which crossed the area on the same day. The water quality profiler was deployed at 9:31 am, about 4 minutes earlier than the Landsat 8 p118 r65 scene center time, which was at 9:35 am. With near real-time measurement only at one site, we were still able to conduct Chl-a data validation by comparing Chl-a from the Landsat 8 OLI images derived with equation (3) with the data from the water quality profiler at a depth of approximately 10 cm from the surface as presented in Table 4.

Due to the limitation of the research equipment, it was only possible to validate the Chl-a concentrations predicted from Landsat 8 OLI using water quality profiler data obtained on 16 August 2020. From equation (4), we obtained an RMSE value of 0.491741. Low RMSE indicates that variation of the values obtained from an estimation/forecast is close to the variation in the observed values. In other words, the smaller is the RMSE value, the closer the predicted values are to the observed ones. Compared with the previous works by Muhsoni et al. (2008) and Nuriya et al. (2010), who have reached RMSE of 1.0631 and 0.934663, the results of this research with RMSE of 0.491741 look much better. RMSE equal to 0 means that predicted and observed values match perfectly, so the value obtained in this research is still not sufficient to fulfill the requirement as the target is to reach RMSE of 0.1.

Meanwhile, the following reasons could explain why the RMSE value obtained from this research only reached 0.491741: (1), only at one location water quality profiler was deployed at the same time with the Landsat 8 OLI satellite image. At other locations, the time was about 1 to 2 hours before and after the satellite crossing the research area because it took some time to move from the sampling location at Nguling to Lekok and then to Kraton with the fisherman boat. (2), it was hardest to match the availability of the water quality profiler from the laboratory with the schedule of Landsat 8 OLI crossing the research area and, as a result, we were only able to conduct one in situ measurements in time at sampling location number 2 (Lekok), (3) the equation applied to predict/estimate Chl-a concentration from Landsat 8 OLI was developed by Bhirawa and Djaelani (2015) for closed waters (lake).

Furthermore, we also applied a different atmospheric correction to get the reflectance values from the DN (digital number). Bhirawa and Jaelani (2015) as well as Jaelani et al. (2016) used 6S for their Landsat imagery while this research only used Landsat standard TOA according to USGS (2019). Sriwongsitanon et al. (2011) and Ye et al. (2017) mentioned that the 6S atmospheric correction model proved to have a better effect on the results while using Landsat imagery. Thus, the results of this research could be improved by applying other atmospheric corrections. Meanwhile, Yadav et al. (2019) estimated Chl-a using Landsat 8 by combining the TOA, mid-latitude summer atmospheric model and maritime aerosol model in the module FLAASH of ENVI 5.2 for further validation of the atmospheric correction. On the other hand, Poddar et al. (2019) used four steps to retrieve Chl-a. The steps included obtaining TOA reflectance, determining surface reflectance from TOA reflectance for the two sensors following Moran et al. (1992), and converting it to the corresponding remote sensing reflectance according to Moses et al. (2015), which is then used in the OC^2 algorithm to get Chl-a.

On the other hand, according to Cui et al. (2020), accurate estimation of Chl-a concentration in coastal waters from the ocean color using remote sensing faces challenges due to the optical complexity if compared with clear oceanic waters. Furthermore, Jaelani et al. (2016) also mentioned that the accuracy of the estimated data depends on an accurate atmospheric correction algorithm and algorithms for determining physical parameters. This statement is remove relevant to the conditions of the water in the research area. Somehow, we were facing turbid water at a few centimeters depth from the surface during the use of the water quality profiler as mentioned earlier. Chl-a data derived from Landsat 8 OLI in turbid water probably would be better if the algorithm of Watanabe et al. (2018) was applied or different algorithms were used for the dry and wet season as conducted by Gholizadeh and Melesse (2017). We consider it as parts for improvement in future works.

CONCLUSIONS

According to the analysis: (1) spatial distribution of chlorophyll-a (Chl-a), its concentration and dynamics in the Madura Strait waters near the Pasuruan coastal area varies between dry and rainy months or seasons, (2) input from rivers, waves, tidal level, and eddy circulation constitute the oceanographic parameters that influence the spatial distribution pattern of chlorophyll-a (Chl-a) in the Madura Strait waters near the Pasuruan coastal area, and (3) validation of the estimated Chl-a concentration from Landsat 8 OLI using field data has shown RMSE value of 0.49.

Table 4. Validation of Chl-a concentration predicted from Landsat 8 OLI vs observed from water quality profiler

No	Location	Observed value from Water Quality Profiler 16 Aug 2020 (A)	Predicted value from Landsat 8 OLI 16 Aug 2020 (B)	A-B
1	Nguling	1.29	2.678	-1.388
2	Lekok	3.01	2.359	0.651
3	Kraton	4.44	2.227	2.213
			RMSE	0.491741

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