FORUM GEOGRAFI
ISSN: 0852-0682 | E-ISSN: 2460-3945

HTTPS://JOURNALS.UMS.AC.ID/INDEX.PHP/FG/

Research article

Analysis of Chlorophyll-a Variability in the Eastern Indonesian Waters Using Sentinel-3 OLCI from 2020-2021

Eko Yuli Handoko[1,2,*], Noorlaila Hayati [1], Muhammad Aldila Syariz[1], Megivareza Putri Hanansyah[1]

[1] Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya 60111, Indonesia

[2] Research Center for Disaster Mitigation and Climate Change, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya 60111, Indonesia

[*)]Correspondence: ekoyh@its.ac.id

Citation:

Handoko, E. Y., Hayati, N., Syariz, M. A, & Hanansyah, M. P. (2024). Chlorophyll-a Variability Using Sentinel-3 OLCI in the East Indonesian Sea 2020-2021. Forum Geografi. 38(1), 74-82.

Article history:
Received: 28 July 2023
Revised: 18 August 2023
Accepted: 4 March 2024
Published: 1 April 2024

Abstract

The Eastern Indonesian waters are significant in influencing the global climate system and oceanic connectivity. However, the Indonesian Through Flow (ITF) facilitates the movement of waters from the Pacific Ocean to the Indian Ocean. This flow vertically mixes water masses in the Eastern regions, leading to the concentration of phytoplankton. In addition, the distribution of phytoplankton, indicative of chlorophyll-a concentration, is influenced by upwelling and downwelling phenomena. Chlorophyll-a, responsible for capturing carbon and producing oxygen in marine ecosystems, is important in regulating climate change. Moreover, oceanographic conditions play a significant role in the dispersion of chlorophyll-a concentration. Therefore, this study adopted ocean colour remote sensing technology to assess chlorophyll-a distribution. Monthly ocean colour data was collected by the multi-temporal Sentinel-3 Ocean and Land Colour Instrument (OLCI). The analysis output included chlorophyll-a concentration associated with currents and the El Nino Southern Oscillation (ENSO). Data processing using the Case-2 Regional Coast Colour (C2RCC) processor resulted in an average chlorophyll-a concentration in the Eastern Indonesian waters ranging from 0.16 to 0.52. The results showed higher chlorophyll-a levels during the southeast monsoon (July to September) and lower levels during the northwest monsoon (January to March).

Keywords: chlorophyll-a; Indonesian through flow; eastern Indonesian waters; Sentinel-3 OLCI; C2RCC.

1. Introduction

The Indonesian waters are significant in influencing the global climate system and inter-ocean interactions. This influence is attributed to the flow of water masses originating from the western Pacific Ocean towards the southeast Indian Ocean, driven by variations in water mass pressure, a phenomenon known as the Indonesian Through Flow (ITF) (Hasanudin, 1998; Sprintall & Révelard, 2014). The flow directs waters towards the Indian Ocean, leading to the replacement of flowing waters by the North Pacific and South Pacific thermocline waters. Therefore, there is an extensive mixing of water masses, termed Mix-Master Indonesia, including chlorophyll, temperature, salinity, oxygen, and other tracers (Gordon, 2005; Nugroho Setiawan *et al.*, 2013).

The Eastern Indonesian waters are a focal point in ITF studies due to their potential for large marine resources and diverse biota habitats (Misgiati *et al.*, 2024). These waters are highly fertile due to the vigorous mixing of water masses (Wisnubroto *et al.*, 2021), a process closely tied to upwelling and downwelling phenomena. Upwelling covers the ascent of water masses from lower to upper layers, while downwelling is the descent of water masses to deeper layers. The southeast monsoon, characterised by wind moving from the Australian Continent to the Asian Continent, significantly influences the annual upwelling in the Indonesian waters (Purba & Khan, 2019).

Chlorophyll, a natural pigment essential for photosynthesis is widespread in various plants (Humphrey, 1980). In many marine environments, it manifests as a green pigment within phytoplankton, which are microscopic plants integral to the marine food web. Chlorophyll plays a crucial role in the environment by absorbing carbon and generating substantial amounts of oxygen. Chlorophyll-a, a predominant type of chlorophyll found in phytoplankton, serves as a primary producer in waters, contributing approximately 95% (Al Diana *et al.*, 2020; Widyorini, 2009). The distribution of chlorophyll-a in the ocean varies both temporally and spatially, contingent upon the oceanographic conditions of the water body (Bramic *et al.*, 2021).

An effective method to monitor the variability of chlorophyll-a distribution over a large area and an extended period is through ocean colour remote sensing satellite technology. Ocean colour, indicative of dissolved or suspended substances, is subjected to changes in response to environmental factors. Meanwhile, ocean colour remote sensing, a passive method using electromagnetic wave radiation, primarily uses visible and Near Infrared (NIR) light (Stierman, 2017). Chlorophyll-a changes the colour of the water to greenish, facilitating the detection of its distribution variations. Therefore, this study adopted ocean colour data from the Sentinel-3 satellite, developed by the European Space Agency (ESA), in support of the Copernicus program. The program was specifically designed in response to user needs for environmental monitoring (ESA, 2021). Sentinel-3 is divided into three instrument sets, including altimetry, thermal, and optical, with the analysis using data from the Ocean and Land Colour Instrument (OLCI).

This study aimed to analyse the variability in the distribution of chlorophyll-a content in the Eastern Indonesia from 2020 to 2021 on a monthly basis. The results will be correlated with geostrophic currents to explain the relationship between chlorophyll-a movement in the ocean and ITF.

2. Methods

The study area was the Eastern Indonesia waters, comprising the Banda, Flores, Sulawesi, Maluku, Seram, Halmahera, Timor, Arafura, and Sawu waters. The area boundary was located at coordinates 6N - 11S and 115E - 141E, as shown in Figure 1.

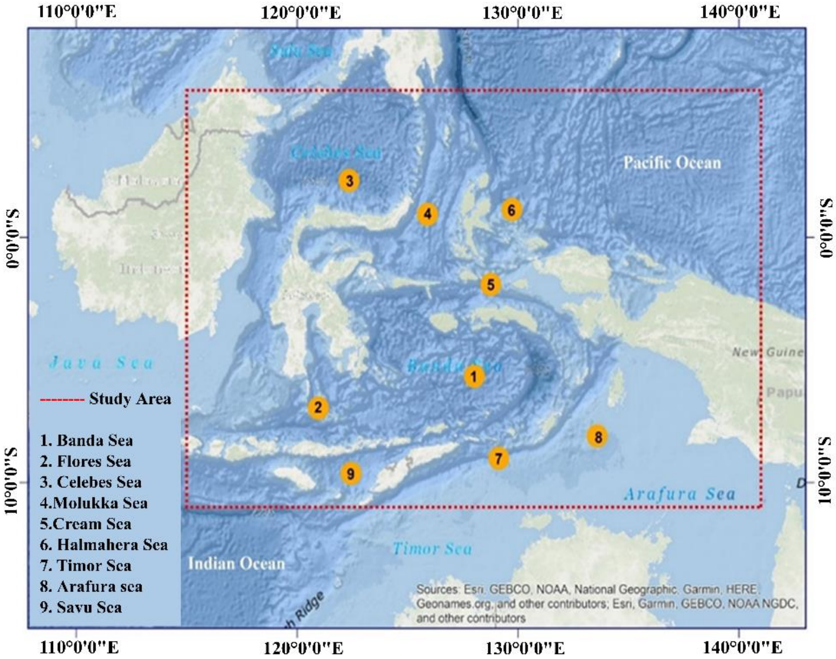

Figure 1. Study Area.

This study required monthly Sentinel-3 OLCI Level 1 Top of Atmosphere (ToA) Radiance Full Resolution image data from 2020 to 2021. The data was processed using the Case-2 Regional Coast Colour (C2RCC) Processor, integrated with the Sentinel Application Platform (SNAP) software (Amankulova *et al.*, 2024). C2RCC served as a processor for atmospheric correction and the calculation of water constituents from optical satellite images (Lumban-gaol *et al.*, 2024). Algorithms within C2RCC Processor determined Inherent Optical Properties (IOP) and calculated concentrations of water constituents (Naves V.H. *et al.*, 2021). A Neural Network (NN) was trained for atmospheric correction and IOP determination, with additional inputs of temperature and salinity data required (Poopipattana c. *et al.*, 2024). Atmospheric correction produced Water Leaving Radiance Reflectance (RLw) (Kulha *et al.*, 2024). The results were then reprocessed by the NN Case 2 Water Processor, providing 5 IOPs, including absorption by phytoplankton pigments. The absorption by phytoplankton pigments at 443 nm was converted to apig, and chlorophyll-a concentration was calculated using Equation 1 (Doerffer, 2010).

$$\text{chla} = 22\_\text{apig}(443)^{1,04} \quad (1)$$

Temperature and salinity data were sourced from the CMEMS Global Ocean Ensemble Reanalysis product and Multi Observation Global Ocean ARMOR3D L4 (Marine Copernicus). The output from the C2RCC process provided a band with chlorophyll-a content, which was subjected to mosaic or image merging, as well as subset cutting according to the study area, and reprojection into the WGS84 system. Cloud masking was subsequently performed to remove cloud cover and ensure it did not affect chlorophyll-a data results.

The accuracy of chlorophyll-a data processing using C2RCC Processor was tested against OC4Me product data obtained from Sentinel-3 Ocean Colour Level 2. The accuracy test adopted Root

Mean Square Error (RMSE) pixel by pixel (An *et al.*, 2020) on Equation 2. Whereas **N** or n is the number of samples or observations, x_p is the Chlorophyll-a data results, and x_v is the actual data.

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(x_p - x_v)^2}{n}} \tag{2}$$

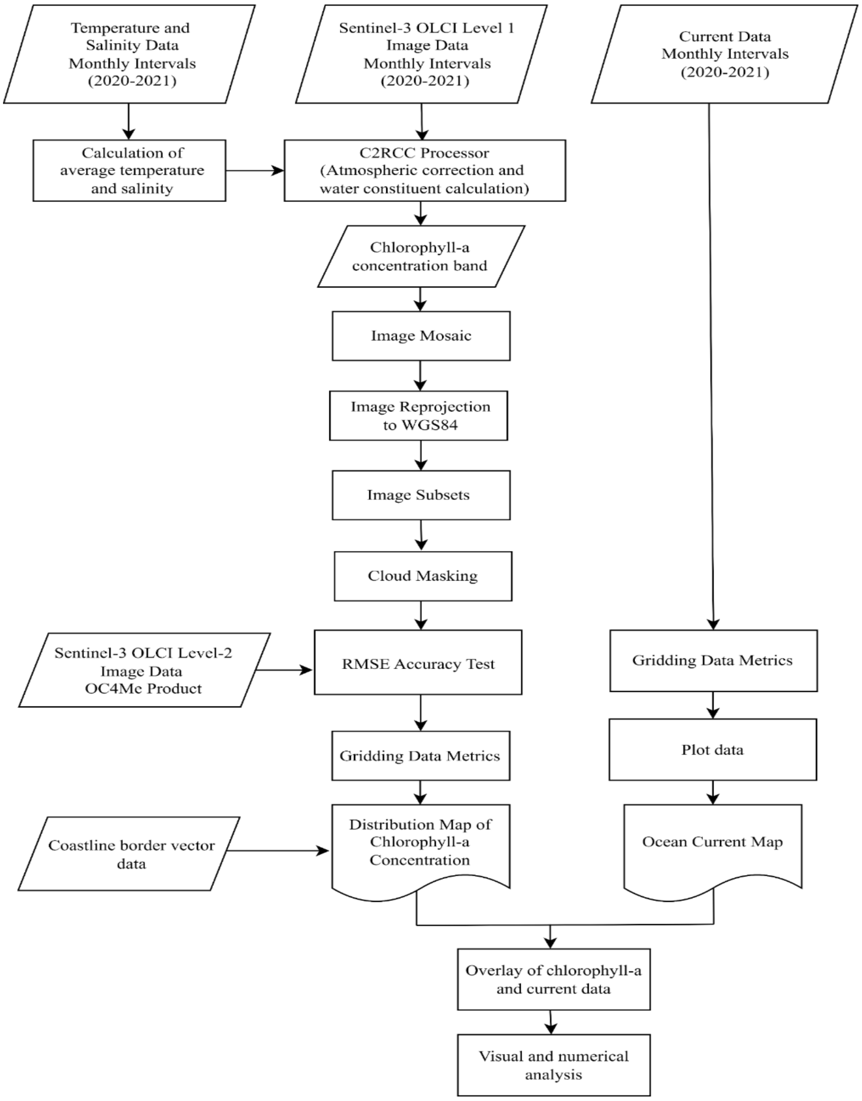

Figure 2. Study workflow.

The data visualisation process was conducted using MATLAB software, and chlorophyll-a data was initially gridded before visualisation. Chlorophyll-a data was subsequently overlaid with currents data retrieved from the Global Total Surface and 15m Currents (Marine Copernicus). The currents data was gridded and was plotted using the vector plot quiver function in MATLAB. The data processing flow in this study was presented in Figure 2.

The final process was to visually and numerically analyse chlorophyll-a distribution's spatial and temporal variability in the Eastern Indonesia waters. The variability of chlorophyll-a would be examined based on phenomena that occurred in the waters.

3. Results and Discussion

3.1. Chlorophyll-a Variability in the Eastern Indonesia Sea 2012-2021

Chlorophyll-a distribution was categorised into five colours, including light green (0.01 - 0.1 mg/m^3), dark green (0.1 - 0.4 mg/m^3), yellow (0.4 - 2 mg/m^3), orange (2 - 10 mg/m^3), and red (10 - 30 mg/m^3). The distribution map in Figure 3 showed white areas, indicating unknown chlorophyll-a concentration due to cloud cover over the Eastern Indonesia during the recording by the Sentinel-3 satellite. Indonesia, with two-thirds of its territory covered by the ocean, often experienced extensive cloud cover (Hermawan, 2015).

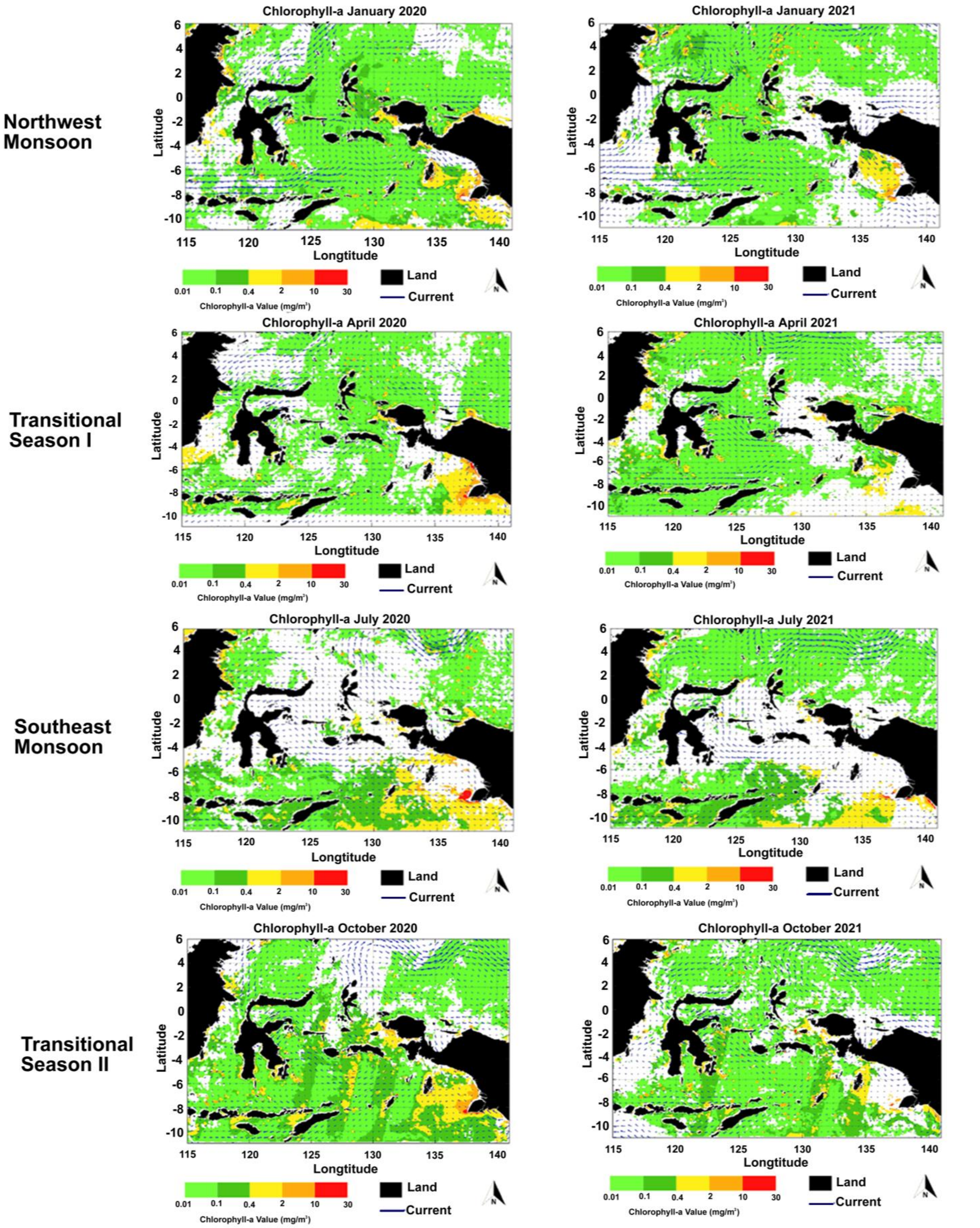

Figure 3. Chlorophyll-a Distribution Map 2020-2021, where (a) is during the northwest monsoon, (b) during the transitional season I, (c) during the Southeast monsoon, and (d) during the transitional season II.

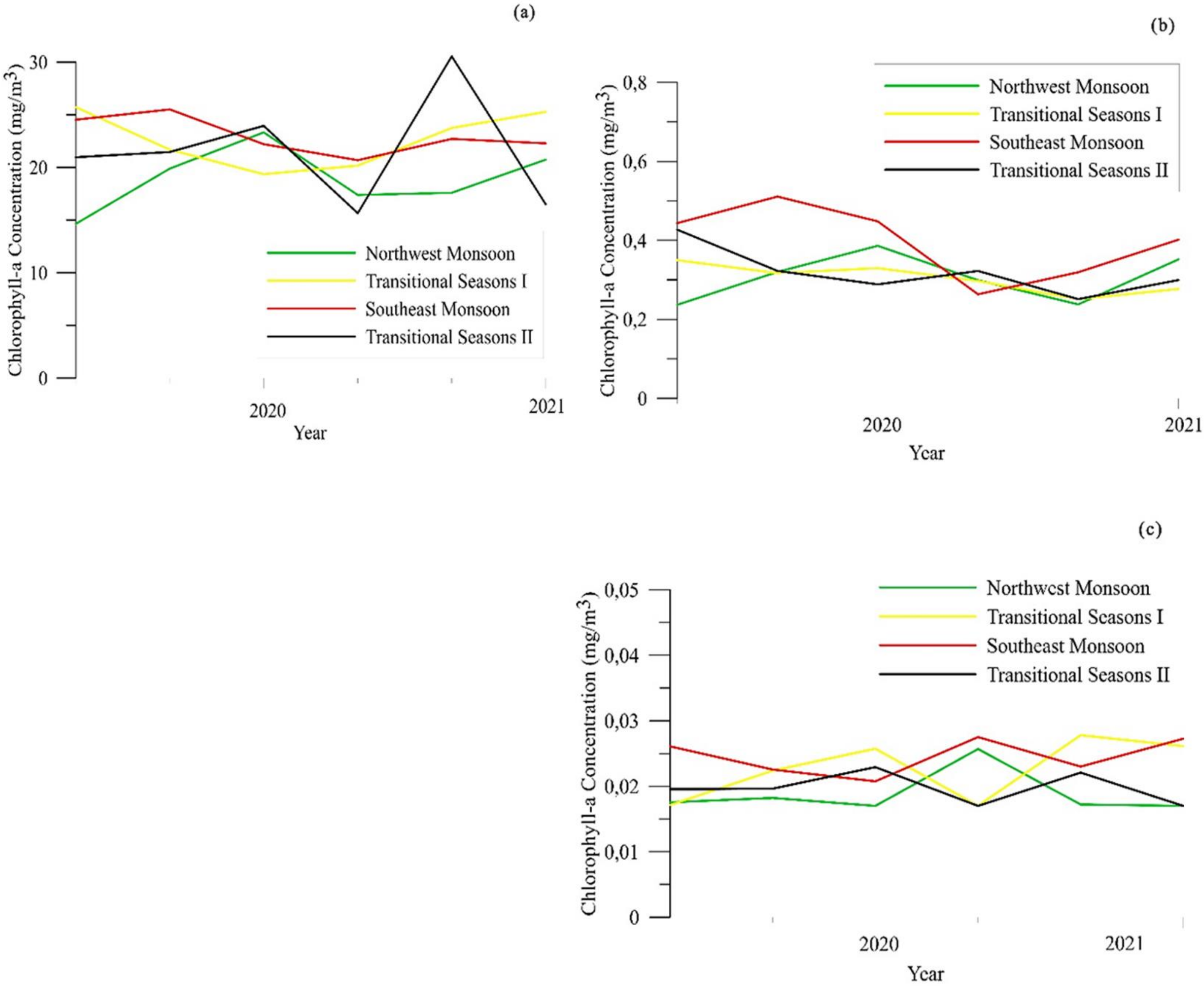

Figure 4. Variations of Chlorophyll-a Concentrations in Eastern Indonesia Waters. (a) Maximum Chlorophill-a in the East Indonesia waters, (b) Average Chlorophill-a in the Eastern Indonesia waters, and minimum (c) Chlorophill-a Minimum in the Eastern Indonesia waters.

Based on Figure 4, the maximum concentration value of chlorophyll-a in the Eastern Indonesia waters ranged from 15.65 – 30 mg/m^3. The average and the minimum concentration values ranged from 0.24 - 0.51 mg/m^3 and 0.02 - 0.03 mg/m^3 respectively. Furthermore, the highest chlorophyll-a concentration during 2020-2021 coincided with the southeast monsoon, gradually decreasing thereafter into the northwest monsoon. The analysis of chlorophyll-a concentrations in Eastern Indonesia waters reveals significant seasonal fluctuations, correlating with the monsoonal shifts. During the southeast monsoon, chlorophyll-a levels peak, reflecting an abundance of marine phytoplankton, before diminishing as the northwest monsoon sets in, showcasing the dynamic nature of marine ecosystems in response to climatic patterns.

Figure 5 presented a map of ocean currents direction distribution during the northeast monsoon, southeast monsoon, and transitional periods. During the northwest monsoon, the currents tended to flow from the Western Pacific Ocean to the East Indian Ocean (south of Java Island), while during the southeast monsoon, they move from the East Indian Ocean (south of Java Island) to the West Pacific Ocean through the Indonesian waters (Hatayama *et al.*,1996; Li *et al.*, 2020). Additionally, ocean currents play a pivotal role in this process, with their direction changing with the monsoons, further influencing the distribution and concentration of chlorophyll-a by transporting nutrients and phytoplankton across the Indonesian archipelago, underscoring the complex interplay between oceanographic conditions and marine biological productivity.

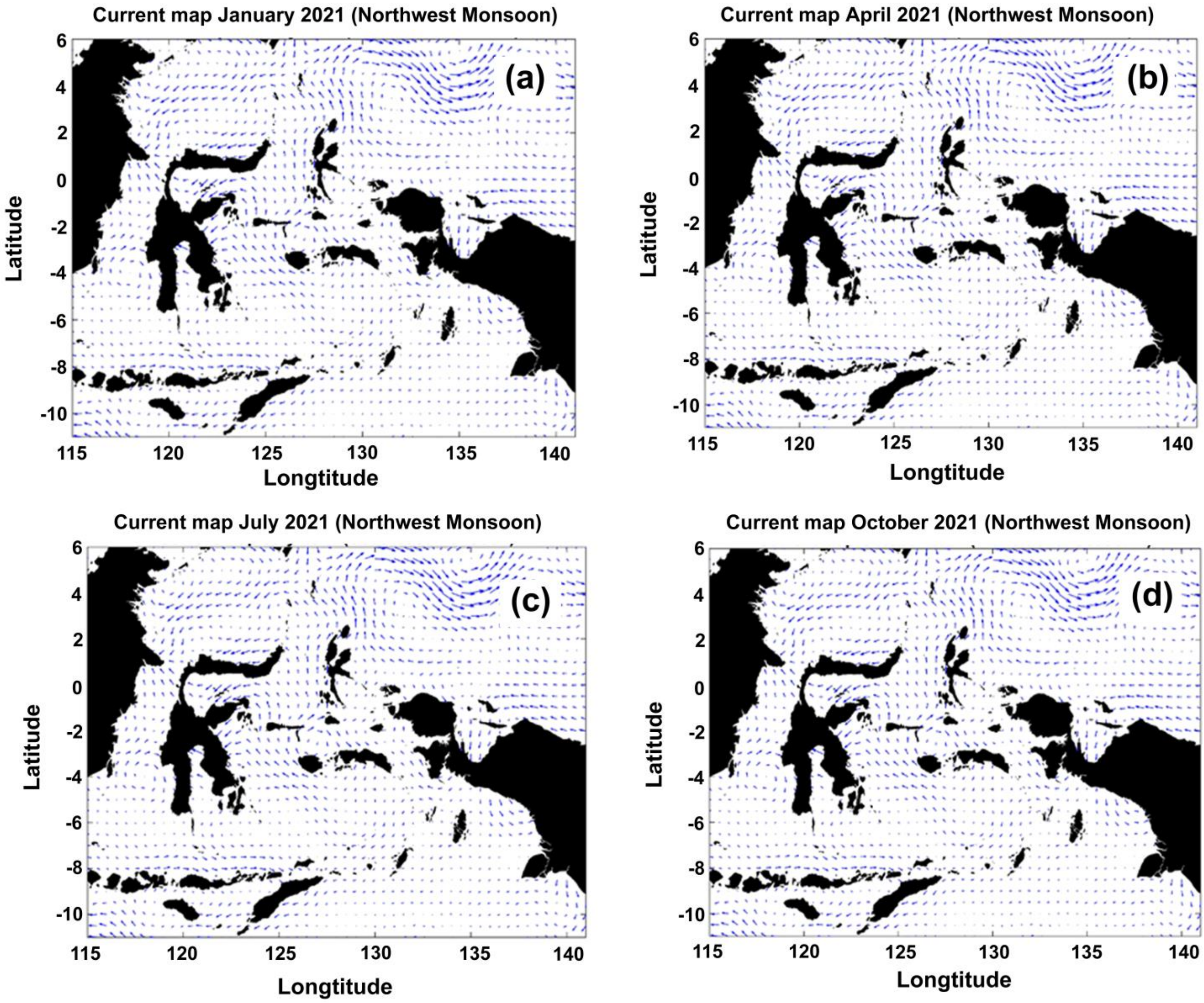

Figure 5. Maps of ocean current direction distribution during northwest monsoon (a), transitional season I (b), southeast monsoon (c), and transitional season II (d).

3.2. Analysis of Chlorophyll-a Distribution

Chlorophyll-a concentration in the Eastern Indonesian waters had spatial and temporal variations, ranging from 0.01 to 30 mg/m^3. Coastal areas typically had higher chlorophyll-a concentration compared to open ocean regions. This could be attributed to coastal upwelling, river nutrient influx, and local environmental conditions (Ningrum *et al*. 2022; Susanto *et al.*,2006; Syahdan *et al*.,2014).

The concentration of chlorophyll-a tended to be high during the southeast monsoon season (June to August). This phenomenon was driven by the movement of currents from the East Indian Ocean (south of Java Island) toward the West Pacific Ocean through the Indonesian waters. The shift in currents was attributed to the sun's position in the northern hemisphere during the Eastern Monsoon period, leading to low pressure in the northern hemisphere and high pressure in the southern hemisphere. Therefore, wind flowed from the southern hemisphere to the northern hemisphere, driving the currents from the East Indian Ocean to the West Pacific Ocean. This movement, influenced by wind, signified the occurrence of upwelling (Gordon, 2005). Upwelling brought colder water masses from the Indian Ocean to the surface in the Indonesian waters, where they mixed with Pacific Ocean masses (Gordon, 2005; Maro *et al.*, 2021; Susanto *et al.*, 2006). The mixing resulted in nutrient-rich conditions that enhanced waters productivity and elevated chlorophyll-a concentration.

During the Western Monsoon (December, January, February), chlorophyll-a concentration typically decreased. This seasonal change was attributed to the prevailing currents direction, which tended to shift from the Western Pacific Ocean toward the East Indian Ocean (South of Java Island) through the Indonesian waters. The shift occurred due to the southern hemisphere receiving more heat and experiencing low pressure during the Western Monsoon period. This resulted in a movement of currents from regions of high pressure in the northern hemisphere toward the southern hemisphere. The movement of currents indicated downwelling (Gordon, 2005), during which nutrient-rich water masses descended to deeper ocean layers. Therefore, waters productivity decreased, leading to a reduction in chlorophyll-a concentration.

This study used the C2RCC processor, an algorithm designed for case 2 waters. The selection of the method considered the diverse waters depths, which comprised both deep and shallow. Additionally, the investigation conducted on the global distribution of case 1 and case 2 indicated that the Eastern Indonesia waters included both types. Therefore, the chlorophyll-a distribution results obtained in this study would be compared with a product for case 1 water from Sentinel-3 Ocean Colour Level 2. The comparison data had been processed with the OC4Me algorithm, specifically designed for case 1 water chlorophyll-a estimation, using a combination of 4-band ESA and modified MERIS legacy for OLCI. The resulting RMSE calculation was 0.43, indicating the weighted average error between the predicted values and verification data in this dataset.

3.3. Analysis of Chlorophyll-a Content in The Arafura and Savu Waters

This study used two samples to monitor changes in the Eastern Indonesian waters, enabling analysis of annual average chlorophyll-a fluctuations. The graph below showed the monthly variations in average chlorophyll-a levels in the Arafura and Savu waters from 2020 - 2021.

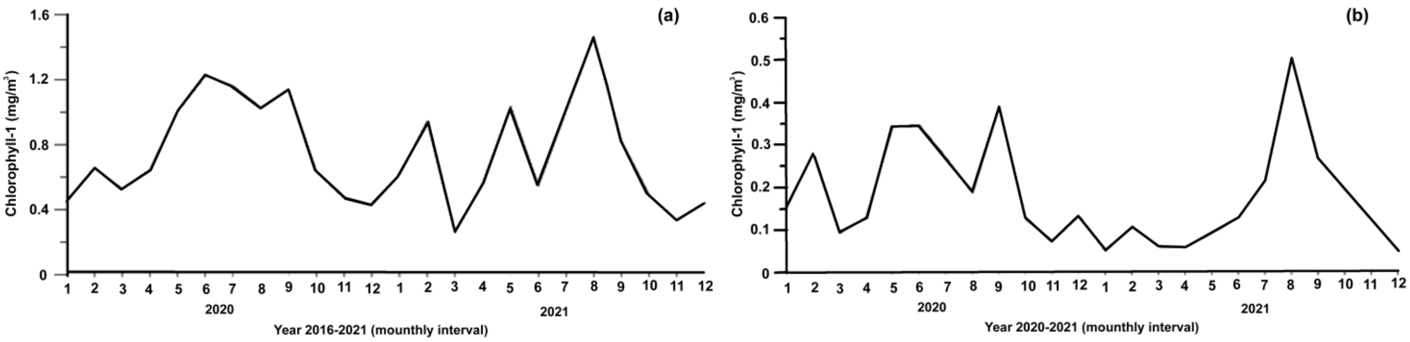

Figure 6. (a) Average chlorophyll-a in Arafura waters samples from 2020 - 2021, (b) Average Chlorophyll-m in the Savu waters samples from 2020 - 2021.

From 2020 to 2021, as shown in Figure 6. (a), the Arafura waters had average chlorophyll-a values ranging from 0.26 to 1.46 mg/m3. In Figure 6. (b), the Savu waters had average values ranging from 0.05 to 0.51 mg/m3. Specifically, the Arafura waters had higher chlorophyll-a concentration compared to the Savu ones, attributed to its shallow nature and status as the primary upwelling spot area in the Eastern Indonesian waters (Purba & Khan, 2019). Both oceanic regions

experienced phases of high and low chlorophyll-a concentration annually, influenced by seasonal variations. The peaks in the concentration typically coincided with the southwest monsoon, while the low phase occurred during the northwest monsoon.

In the Arafura waters, chlorophyll-a concentration peaked in June 2020 and August 2021, coinciding with the southeast monsoon. The lowest concentration, on the other hand, were recorded in December 2020 (northwest monsoon) and May 2021 (transitional season I). In the Savu waters, chlorophyll-a concentration peaked in September 2020 (transitional season II) and August 2021 (southeast monsoon), with the lowest values observed in December 2020 and 2021. These patterns were in line with the seasonal monsoon cycles in Indonesia, where the east monsoon prevailed from April to October, and the west monsoon dominated from October to April (Hermawan, 2015).

3.4. Discussion

The Mix-Master Indonesia phenomenon arose from the exchange of water masses between the western Pacific Ocean and the southeast Indian Ocean, facilitated by the pressure-differential mechanism of ITF (Edwards & Yukio, 2020). Therefore, this study focused on the Eastern Indonesian waters, renowned for their rich marine resources and diverse habitats. Due to the vigorous mixing of water masses, these waters were fertile. An examination of the upwelling and downwelling phenomena, particularly during the Southeast Monsoon, offered insights into how seasonal fluctuations affect the biological productivity of the areas. This ecological comprehension was essential for conservation and sustainable marine management.

The application of ocean colour remote sensing satellite technology, particularly using Sentinel-3 satellite data, enabled the efficient monitoring of chlorophyll-a distribution over extended periods and expansive spatial dimensions. The use of Sentinel-3, equipped with the OLCI, signified the collaborative potential of advanced satellite technology and environmental surveillance. Correlated with monsoonal phases, the distribution maps indicated the dynamic nature of chlorophyll-a concentration. The examination was further enhanced by correlating it with geostrophic currents, providing a complex understanding of the relationship between chlorophyll-a dynamics influenced by the ITF and waters movement.

An analysis of chlorophyll-a concentration in the Arafura and Savu waters offered a more regional perspective, as indicated by Nurfitri (2021). The temporal analysis uncovered distinct patterns in each water, with variations corresponding to monsoonal phases. The disparity in chlorophyll-a levels between the Savu and Arafura waters arose from the shallow nature of the Arafura and its designation as an upwelling hotspot.

4. Conclusion

In conclusion, the distribution of chlorophyll-a in the Eastern Indonesian waters had spatial and temporal variability. Chlorophyll-a concentration tended to be higher during the southeast monsoon, typically from June to August, and lower during the northwest monsoon, generally from December to February. From 2020 to 2021, the maximum concentration value in Eastern Indonesian Waters ranged from 15.65 – 30 mg/m^3. The average and the minimum chlorophyll-a concentration ranged from 0.24 - 0.51 mg/m^3 and 0.02 - 0.03 mg/m^3, respectively.

Acknowledgements

The authors are grateful to Copernicus for providing Sentinel Data.

Author Contributions

Conceptualisation: Handoko, E. Y, Syariz, M. A., Hayati, N.; **methodology:** Handoko, E. Y. Syariz,M. A., Hayati, N., Hanansyah, M. P.; **investigation:** Handoko, E. Y. Syariz,M. A., Hayati, N., Hanansyah, M. P.; **writing original draft preparation:** Handoko, E. Y. Syariz,M. A., Hayati, N., Hanansyah, M. P.; **writing review and editing:** Handoko, E. Y. Syariz,M. A., Hayati, N., Hanansyah, M. P.; **visualisation**: MAS, MPH. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

Funding

This study was funded by:

Directorate of Research and Community Service, Institut Teknologi Sepuluh Nopember (ITS), Ministry of Education and Culture, Research and Technology in accordance with the ITS Fund Partnership Research Implementation Agreement Batch 2 Year 2023 Master Contract Number: 2247/PKS/ITS/2023, dated June 26, 2023; Researcher Contract Number: 2250/PKS/ITS/2023, dated June 26, 2023

References

Aldiana, N. Z., Sari, L. A., Arsad, S., Pursetyo, K. T., & Cahyoko, Y. (2020). Monitoring of Phytoplankton Abundance and Chlorophyll-a Content in the Estuary of Banjar Kemuning River, Sidoarjo Regency, East Java. *Journal of Ecological Engineering*, 22(1), 29–35. doi: 10.12911/22998993/128877.

Amankulova, K., Farmonov, N., Omonov, K., Abdurakhimova, M., & Mucsi, L. (2024). Integrating the Sentinel-1, Sentinel-2 and topographic data into soybean yield modelling using machine learning. *Advances in Space Research*, 73(2024), 4052–4066. doi: 10.1016/j.asr.2024.01.040

An, G., Xing, M., He, B., Liao, C., Huang, X., Shang, J., & Kang, H. (2020). Using Machine Learning for Estima-ting Rice Chlorophyll Content from In Situ Hyperspectral Data. *Remote Sensing*, 12(18), 1-22. doi: 10.3390/RS12183104.

Bramich, J., Bolch, C. J., & Fischer, A. (2021). Improved red-edge chlorophyll-a detection for Sentinel 2. *Ecological Indicators*, 120, 106876. doi: 10.1016/j.ecolind.2020.106876.

Doerffer, R. (2010). *Sentinel-3 L2 Products And Algorithm Definition Olci L2 ATBD Ocean Co-lour Turbid Water OLCI Level 2 Ocean Colour Turbid Water*. GKSS Research Center . https://sentinels.copernicus.eu/web/sentinel/user-guides/sentinel-3-olci/document-library/-/asset_publisher/hkf7sg9Ny1d5/content/sentinel-3-olci-ocean-colour-turbid-water-atbd.

ESA. (2021). *Copernicus Sentinel-3 OLCI Land User Handbook*. Sentinel Online . https://sentinels.copernicus.eu/web /sentinel/user-guides/sentinel-3-olci/document-library/-/asset_publisher/hkf7sg9Ny1d5/content/id/4598138.

Edwards, T., & Yukio M. (2020). The Indonesian throughflow and its impact on biogeochemistry in the Indone-sian seas. *ASEAN Journal on Science and Technology for Development*, 37(1), 29-35. doi: 10.29037/ajstd.596.

Gordon, A. L. (2005). Oceanography of the Indonesian Seas and Their Throughflow. *Oceanography*, 18(4), 14–27. doi : 10.5670/oceanog.2005.01.

Hasanudin, O. M. (1998). Arus Llntas Indonesia (ARLINDO): Vol. XXIII (Issue 2). www.oseanografi.lipi.go.id.

Hatayama, T., Awaji, T., & Akitomo, K. (1996). *Tidal currents in the Indonesian Seas and their effect on transport and mixing*. Journal of Geophysical Research: Oceans, 101(C5), 12353-12373.

Hermawan, E. (2015). *Indeks Monsun Asia-Australia dan Aplikasinya*. LIPI Press. https://penerbit.brin.go.id/ press/catalog/view/38/385/5528.

Kulha, N., Ruha L., Väkevä,S., Koponen,S., Viitasalo M., and Virtanen, E. A. (2024). Satellite bathymetry estimation in the optically complex northern Baltic Sea. *Estuarine, Coastal and Shelf Science*, 298, 108634. doi: 10.1016/j.ecss.2024.108634.

Li, M., Gordon, A. L., Gruenburg, L. K., Wei, J., & Yang, S. (2020). Interannual to decadal response of the Indonesian throughflow vertical profile to Indo-Pacific forcing. *Geophysical Research Letters*, 47(11), e2020GL087679. doi: 10.1029/2020GL087679.

Lumban-gaol, J., Tetuko, J., Sumantyo, S., Tambunan, E., and Situmorang, D. (2024). Sea Level Rise , Land Subsidence , and Flood Disaster Vulnerability Assessment : A Case Study in Medan City , Indonesia. *Remote Sensing*, 16(865), 1–18. doi: 10.3390/rs16050865.

Maro, J. F., Hartoko, A., Anggoro, S., Muskananfola, M. R., & Nugraha, E. (2021). Sea surface temperature and chlorophyll-a concentrations from MODIS satellite data and presence of cetaceans in Savu, Indonesia. *AACL Bioflux*, 14(3), 1190–1200.

Misgiati, W. I., Murniasih, T., Novriyanti, E., Tarman, K., Safithri, M., Setyaningsih, I., Cahyati, D., Pratama, B. P., & Wirawati, I. (2024). The anticancer and antioxidant potential of local sea cucumber Holothuria edulis, an ecology balancer of Labuan Bajo marine ecosystem. *Case Studies in Chemical and Environmental Engineering*, 9, 100625. doi: 10.1016/j.cscee.2024.100625.

Neves, V. H., Pace, G., Delegido, J., & Antunes, S. C. (2021). Chlorophyll and suspended solids estimation in Portuguese reservoirs (Aguieira and Alqueva) from Sentinel-2 imagery. *Water*, 13(18), 2479. doi: 10.3390/w13182479.

Ningrum, D., Zainuri, M., & Widiaratih, R. (2022). Variabilitas Bulanan Klorofil-A Dan Suhu Permukaan Laut pada Perairan Teluk Rembang Dengan Menggunakan Citra Sentinel-3. *Indonesian Journal of Ocea-nography*, 4(2), 88-96. doi: 10.14710/ijoce.v4i2.14258.

Nurfitri, S. (2021). *Physical mechanisms of nutrient supply and controlling factors of phytoplankton growth in the Arafura Sea*. Doctoral dissertation, Staats-und Universitätsbibliothek Hamburg Carl von Ossietzky. Retrived From https://ediss.sub.uni-hamburg.de/handle/ediss/9411..

Nugroho, S. A., Dhahiyat, Y., Primadona Purba Program Studi Ilmu Kelautan, N., Perikanan dan Ilmu Kelautan, F., Padjadjaran, U., Raya Bandung-Sumedang Km, J., & Ubr, B. (2013). Variasi sebaran su-hu dan klorofil-a akibat pengaruh Arlindo terhadap distribusi ikan cakalang di Selat Lombok Variation of temperature and chlorophyll-a due toIndonesian throughflow on skipjack distribution in Lombok Strait. *Jurmal Ilmu Ilmu Perairan, Pesisir, dan Perikanan.* doi: 10.13170/depik.2.2.723.

Purba, N. P., & Khan, A. M. A. (2019). *Upwelling session in Indonesia Waters*. World News of Natural Sciences. Retrived From www.worldnewsnaturalsciences.com.

Poopipattana, C, Suzuki, M., Kumar, M. F. H. (2024). Prediction of Sunlight- and Salinity-Driven Inactivation Kinetics of Microbial Indicators with Validation in a 3D Water Quality Model. *Water MDPI*, 16(3), 1–13. doi: 10.3390/w16030437.

Sprintall, J., & Révelard, A. (2014). The Indonesian Throughflow response to Indo-Pacific climate variability. *Journal of Geophysical Research: Oceans*, 119(2), 1161–1175. doi: 10.1002/2013JC009533.

Stierman, E. M. J. (2017). *Remote sensing of North Sea water quality A comparison between Sentinel-OLCI and in-situ measurements*. Retrived From http://repository.tudelft.nl/.

Susanto, R. D., Moore, II, T. S., & Marra, J. (2006). Ocean color variability in the Indonesian Seas during the SeaWiFS era. *Geochemistry, Geophysics, Geosystems*, 7(5), 1-16. doi : 10.1029/2005GC001009.

Syahdan, M., Atmadipoera, A. S., Susilo, S. B., & Gaol, J. L. (2014). Variability of surface chlorophyll-a in the Makassar Strait–Java Sea, Indonesia. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, 14(2), 103-116.

Widyorini, N. (2009). Pattern of Phytoplankton Community Structure Based on Pigment Content in Jepara Beach. *Journal of Fisheries Science*, 4(2), 69–75. doi: 10.13057/biodiv/d180311.

Wisnubroto, K., Nuraini, R., & Sari E. I. (2021). *Menguak Arus Laut Timur Indonesia*. Portal Informasi Indonesia. Retrived From https://indonesia.go.id/search?keyword=Menguak+Arus+Laut+Timur+Indonesia.