COMPARING OCEANOGRAPHIC PARAMETERS IN DIFFERENT ENSO PHASE AT INDONESIAN SEAS USING MODIS - AQUA

Seftiawan Samsu Rijal (1), Hamim Zaky Hadibasyir (2)

[1] Marine Science, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang, Indonesia
[2] Faculty of Geography, Universitas Muhammadiyah Surakarta, Surakarta, Indonesia
Email: seftiawan.sr@ub.ac.id ; hamim.zaky.h@ums.ac.id

KEYWORDS: ENSO, Oceanography, MODIS - Aqua, Google Earth Engine, Paired Sample T-test

ABSTRACT: El Nino-Southern Oscillation (ENSO) as a global climate variability could have an impact on the condition of an oceanographic parameter. It consists of three phases, El Nino, Neutral, or La Nina. During El Nino, sea level pressure tends to be lower in the eastern Pacific and higher in the western Pacific. The west to east flow drives warm equatorial waters from the western Pacific towards the eastern Pacific and northern South America. Hence, during the El Nino phase, the ocean surface is warming and the temperature is getting higher. While the opposite condition tends to occur during La Nina.

As an archipelagic state and located in the equator, Indonesia experiences the direct impact of ENSO variability to the weather, such as increasing or decreasing rainfall and the warmer or cooler ocean. This study compares the oceanographic parameters based on the ENSO phases in the Indonesian seas, especially at Makassar Strait and its surrounding areas for 2010, 2012, and 2015 as representatives for La Nina, Neutral, and El Nino, respectively.

Four oceanographic parameters were investigated in this paper, i.e. chlorophyll-a, Sea Surface Temperature (SST), Normalized Fluorescence Line Height (NFLH), and Particulate Organic Carbon (POC). All of them were extracted from MODIS - Aqua through the Google Earth Engine portal. Then, the data was processed through the JavaScript command. The statistical method of paired sample T-test was deployed to compare pairs of mean pixel values from the El Nino, Neutral, and La Nina phases for each oceanographic parameter. For example, SST-La Nina VS SST-Neutral, SST-El Nino VS SST-Neutral, SST-La Nina VS SST-El Nino, and so forth. As a result, there were 12 combinations compared in total.

The results show that all of the pairs tested have a significant correlation which ranges from 0.73 to 0.94. This indicates the spatial variations of all oceanic parameters during the three phases of ENSO are relatively constant. In terms of mean differences of oceanographic parameters tested during three phases of ENSO, all of the combinations tested were statistically significant to be different from one another which is indicated by a p-value less than 0.05, except for the combinations of chlorophyll-a-La Nina VS chlorophyll-a-El Nino and NFLH-La Nina VS NFLH-El Nino. Consequently, most of the oceanic parameters investigated have significant differences in terms of mean values for different ENSO conditions in the study areas. The variability of the oceanographic parameters due to changes in ENSO conditions could bring an impact on the dynamics and viability of living organisms in the sea.

1. INTRODUCTION

1.1. Research Background

El Niño-Southern Oscillation (ENSO) is the tropical climate variability that has an impact on the many aspects of human life. According to (Mohtar et al., 2020) at least, ENSO's impact will occur on human health, infrastructure, food security as well as oceanographic parameters. ENSO has three phases in which every single phase has a different effect on the environment. The phases are El Niño, Neutral, and La Niña. These are quasiperiodic climate patterns that arise across the tropical Pacific Ocean on the coast of Peru and Ecuador every five years. El Niño described the warm phase of the ocean, while La Niña described the cold phase (Gómez-Aguilar, 2020).

The variability of the ocean conditions due to ENSO events is very uncertain and such a challenge to investigate. Some of the papers already prove that ENSO will lead to changing any aspect of the oceanographic parameters such as phytoplankton (Racault et al., 2017), sea surface temperature (Sutton, 2018), and salinity (Corvianawatie et al., 2014). However, these parameters themselves need to be compared in different ENSO phases to build the prediction of its behavior by ENSO pattern in several years. In this paper, we aim to evaluate the variability of oceanographic parameters by comparing them in several years of different ENSO phases based on remote sensing imagery and by means of descriptive statistics and paired sample t-test.

2. METHODS

2.1. Research Location

The research conducted in the Fisheries Management Areas (FMA) 713 of Indonesia. The national government divides Indonesian seas into several FMA, as a total there are 11 FMA. FMA is designated based on ocean characteristics, sea toponym, underwater morphology, and Indonesian maritime border. FMA 713 covers several sea, strait, and bay, i.e. Makassar strait, Bone bay, Flores sea, and Bali sea. FMA 713 has a lot of fishery potential (Koeshendrajana, Rusastra, & Martosubroto, 2019) and one of the routes of Indonesian Throughflow (ITF) which plays an important role in global climate due to allowing movement of warm freshwater from the Pacific Ocean to the Indian Ocean at low latitude. FMA 13 is depicted below.

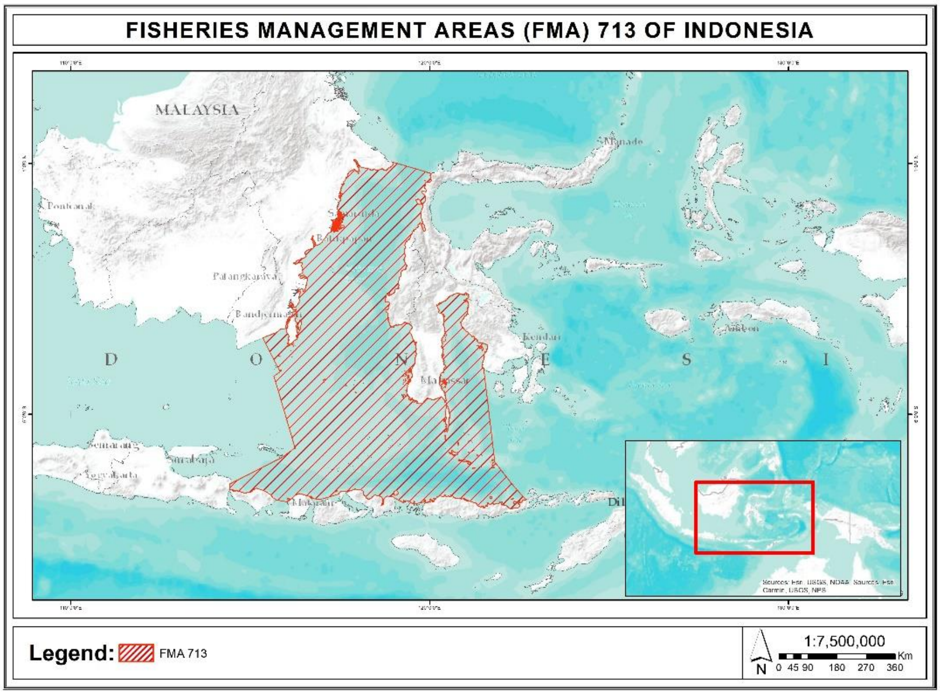


Figure 1. Research Location (FMA 713)

2.2. MODIS – Aqua

MODIS – Aqua data in Google Earth Engine (GEE) includes the catalog of Ocean Color Standard Mapped Image (SMI) MODIS Aqua Data. Dataset available from 2002 July until 2020 July. It is a level 3 product and may be used for studying biology, hydrology of coastal zones, coastal marine habitats, biogeochemical fluxes, and their impacts on the climate and environmental variability. Spatial resolution is about 500 meters with 14 bands. Some of the bands are ready to use e.g. Chlor-a, NFLH (Normalized Fluorescence Line Height), POC (Particulate Organic Carbon), and SST (Sea Surface Temperature. These bands directly represent each condition of oceanic parameters without prior image processing further ado. However, in this research, we directly use it to compare each parameter at different ENSO phases. While other bands are remote sensing reflectance wavelength range from 412 nm up to 678 nm (Table 1).

Table 1. MODIS – Aqua Specification

Name	Units	Min	Max	Wavelength	Description
chlor_a	mg m-3	0*	99.99*		Chlorophyll a concentration
NFLH	mW cm-2 µm-1 sr-1	-0.5*	5.03*		Normalized fluorescence line-height
POC	mg m-3	-2147.48*	12953.4*		Particulate organic carbon
Rrs_412	sr-1	0*	0.11*	412nm	Remote sensing reflectance at band 412nm
Rrs_443	sr-1	0*	0.08*	443nm	Remote sensing reflectance at band 443nm
Rrs_469	sr-1	0*	0.08*	469nm	Remote sensing reflectance at band 469nm
Rrs_488	sr-1	0*	0.08*	488nm	Remote sensing reflectance at band 488nm
Rrs_531	sr-1	0*	0.07*	531nm	Remote sensing reflectance at band 531nm
Rrs_547	sr-1	0*	0.07*	547nm	Remote sensing reflectance at band 547nm
Rrs_555	sr-1	0*	0.07*	555nm	Remote sensing reflectance at band 555nm
Rrs_645	sr-1	0*	0.05*	645nm	Remote sensing reflectance at band 645nm
Rrs_667	sr-1	0*	0.04*	667nm	Remote sensing reflectance at band 667nm
Rrs_678	sr-1	0*	0.04*	678nm	Remote sensing reflectance at band 678nm
SST	°C	-2*	40*		Sea surface temperature

* = estimated min or max value

2.3. Google Earth Engine

Google Earth Engine (GEE) is a cloud computing platform to analyze and visualize about 7 petabytes of public satellite imagery (Gorelick et al., 2017). It was designated for academic, non-profit, business, and government users. GEE runs utilizing JavaScript and Python, the ability to use both or each language programming is necessary once we want to process the image. All of the technical imagery processes that need to execute must be written into source code and it can set access to the public as we provide in Table 2. Imagery processing on the GEE starts with the defining boundary of the research location. Then, it needs to specify on which dataset, bands, and color we want to use. If it is already appropriate, run the code of image downloading and it will directly store on Google Drive. Some image manipulation and layout were done by GIS desktop software.

Table 2. GEE Source Code

Oceanographic Parameters	Source Code Link
Chlorophyll-a	https://code.earthengine.google.com/705a6733fbacfea6b9424d03049697cc
Sea Surface Temperature (SST)	https://code.earthengine.google.com/74a0ef971296415a77ff74ffe3cf16c0
Normalized Fluorescence Line Height (NFLH)	https://code.earthengine.google.com/4ea9b70b528e1296c8f9135efd22b119
Particulate Organic Carbon (POC)	https://code.earthengine.google.com/9164aff585a4c2c3e39209da1b43be52

2.4. Data Analysis

This study compared oceanographic parameters consisting of chlorophyll-a (CHL), Sea Surface Temperature (SST), Normalized Fluorescence Line Height (NFLH), and Particulate Organic Carbon (POC) during June to December 2010, 2012, and 2015. The time of the study was taken with the consideration that from June to December 2010, 2012, and 2015 experienced strong La Nina, neutral ENSO, and strong El Nino conditions, respectively, to obtain a comparison of the conditions of these marine parameters under various climatic conditions.

The mean value of oceanographic parameters in various climatic (ENSO) conditions (La Nina, Neutral, El Nino) was compared using a paired sample t-test to obtain statistical test pairs in the form of SST-La Nina VS SST-Neutral, SST-El Nino VS SST-Neutral, SST-La Nina VS SST-El Nino, and so forth. For the statistical test process, sampling was carried out using a systematic sampling method with intervals between 50 km pixels to represent the whole study areas. In total, 12 combinations of oceanographic parameters under various climatic conditions were compared. Besides, correlation analysis was also carried out for each pair being compared to determine whether there is a significant relationship regarding the distribution of values for oceanographic parameters in various ENSO scenarios. Furthermore, spatial analysis of the distribution of oceanographic parameters in various climatic conditions was also carried out to elaborate on the statistical analysis. The research flowchart is presented in Figure 2.

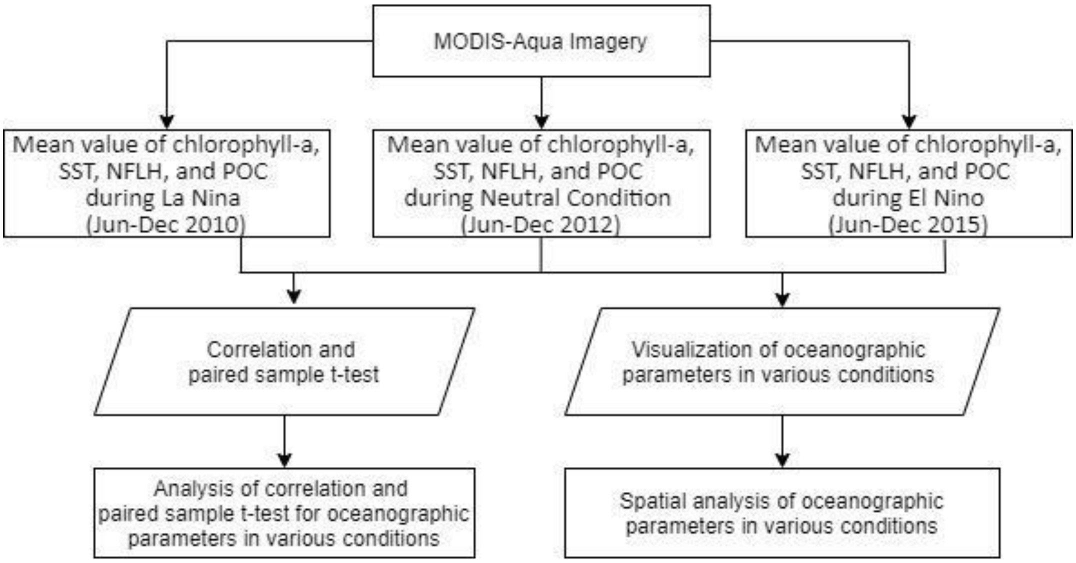


Figure 2. Research Flowchart

3. RESULTS AND DISCUSSION

3.1. Descriptive Statistics

Based on the results of data processing using descriptive statistics on a sample of 471 pixels distributed throughout the study area, we obtained basic information such as the minimum, maximum, average, and standard deviation values for all oceanographic parameters in various ENSO conditions (Table 3). The results of descriptive statistics were then used to determine the difference in the mean value of each parameter by considering the size of the standard deviation.

All of the oceanographic parameters that were evaluated in this research play an important role in the marine ecosystem. Chlorophyll-a is an indicator of phytoplankton abundance and biomass in coastal and estuarine waters. Normalized Fluorescence Line Height (NFLH) provides a rich source of physiological information of phytoplankton (Behrenfeld et al., 2009). Particulate Organic Carbon (POC) or Particulate Organic Matter (POM) can be defined as a living and/or non-living matter of biological origin with a size of ≥ 0.2 µm. Understanding of POC/POM will be very essential to predict the marine ecosystem, food web dynamics, and global biochemical cycles. And the last is Sea Surfaces Temperature (SST) which is related to ocean heat content, an important topic in global warming also one indicator of habitat suitability from many ocean creatures. Each of the parameters has a certain level of quality standards that could lead to a suitable environment for the marine ecosystem (Aryaguna, 2019). Our samples have a range of SST about 26 – 31 °C, Chlorophyll-a is < 15 mg/m^{-3}, NFLH is 0,001 – 1,515 mW cm^{-2} µm^{-1} sr^{-1}, and POC is 35,69 – 720,370 mg/m^{-3}. According to the Indonesian Minister Decree of Environment, this condition is a fine environment to live in for marine creatures (Kementerian Lingkungan Hidup, 2014; Wirasatriya, 2011).

Table 3. Descriptive Statistics for All Parameter Under Investigation Across Various ENSO Conditions

Parameters	N	Minimum	Maximum	Mean	Std. Deviation
M_CHL_LNA	471	0.118	9.521	0.464	0.984
M_CHL_NOR	471	0.123	10.742	0.405	0.853
M_CHL_ENO	471	0.139	8.971	0.487	0.852
M_NFLH_LNA	471	0.001	1.515	0.068	0.084
M_NFLH_NOR	471	0.002	0.645	0.059	0.052
M_NFLH_ENO	471	0.008	0.881	0.066	0.067
M_POC_LNA	471	35.692	605.011	87.294	68.714
M_POC_NOR	471	41.712	558.233	81.248	55.572
M_POC_ENO	471	45.268	720.370	108.201	90.721
M_SST_LNA	471	28.435	31.910	29.946	0.508
M_SST_NOR	471	26.680	31.209	29.314	0.725
M_SST_ENO	471	26.671	30.959	28.942	0.768

(M = mean, CHL = chlorophyll-a (mg m^{-3}), NFLH = Normalized Fluorescence Line Height (mW cm^{-2} μm^{-1} sr^{-1}), POC = Particulate Organic Carbon (mg m^{-3}), SST = Sea Surface Temperature (°C); LNA = La Nina, NOR = Neutral Condition, ENO = El Nino).

3.2. Correlation and Paired Sample t-test

In terms of mean differences of oceanographic parameters tested during three phases of ENSO, all of the combinations tested were statistically significant to be different from one another which is indicated by a p-value less than 0.05, except for the combinations of chlorophyll-a-La Nina VS chlorophyll-a-El Nino and NFLH-La Nina VS NFLH-El Nino (Table 4). One thing that should be noted, the conclusion whether a pair having significant differences is not only based on the mean value, but also the standard deviation.

According to the p-value result, dominantly there is an effect of ENSO to the oceanic parameters in FMA 713 in terms of increasing or decreasing the amount, except for chlorophyll-a and NFLH. Probably for these two, ENSO is not one of the most determinant factors which trigger the changes of those oceanographic parameters. Chlorophyll-a and NFLH could experience increasing or decreasing by another determinant factor except for ENSO such as sunlight, nutrients concentrations near the coastline, and amount of mixing for chlorophyll-a (Jamshidi & Bin Abu Bakar, 2011). Whereas, NFLH may be affected by the high turbidity of the atmosphere which is drive by the suspended aerosol particles (Al Shehhi, Gherboudj, Zhao, Mezhoud, & Ghedira, 2013).

Table 4. Results of Correlation and Paired Sample T-Test

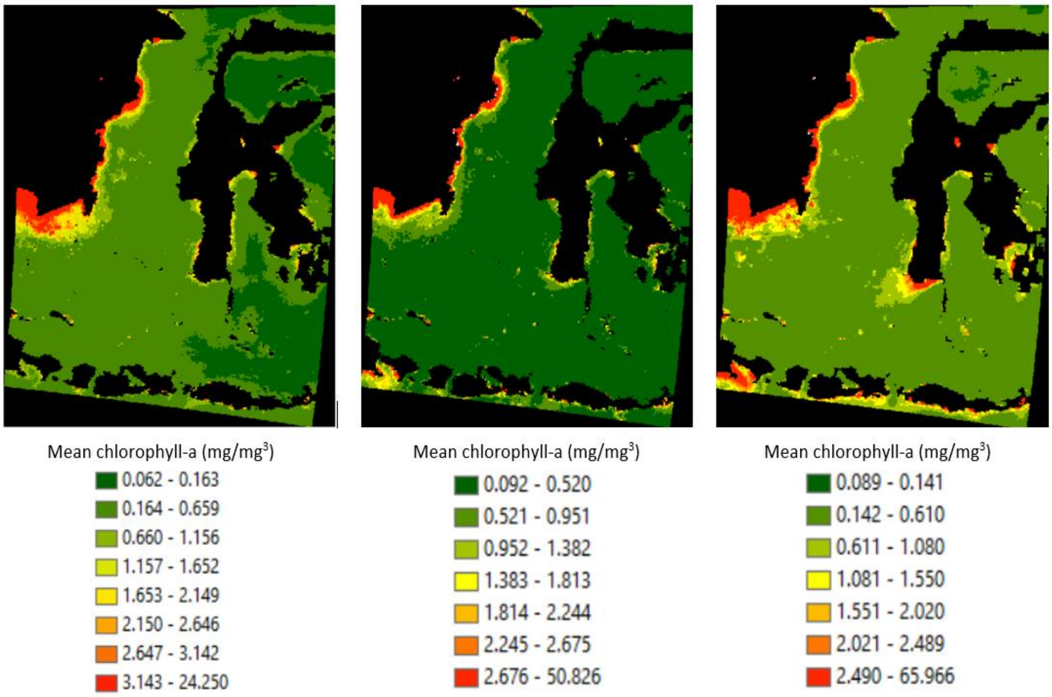
No.	Pairs	Correlation	Mean Difference	P-value of Paired T-test
1	M_CHL_LNA & M_CHL_NOR	0.92	0.058	0.00
2	M_CHL_NOR & M_CHL_ENO	0.92	-0.081	0.00
3	**M_CHL_LNA & M_CHL_ENO**	**0.88**	**-0.023**	**0.29**
4	M_NFL_LNA & M_NFL_NOR	0.86	0.009	0.00
5	M_NFL_NOR & M_NFL_ENO	0.94	-0.007	0.00
6	**M_NFL_LNA & M_NFL_ENO**	**0.87**	**0.002**	**0.32**
7	M_POC_LNA & M_POC_NOR	0.89	6.046	0.00
8	M_POC_NOR & M_POC_ENO	0.75	-26.953	0.00
9	M_POC_LNA & M_POC_ENO	0.73	-20.907	0.00
10	M_SST_LNA & M_SST_NOR	0.86	0.632	0.00
11	M_SST_NOR & M_SST_ENO	0.95	0.372	0.00
12	M_SST_LNA & M_SST_ENO	0.77	1.004	0.00

Bold characters indicate pairs with an insignificant mean difference

3.3. Spatial Variability

The results show that all of the pairs tested have a significant correlation which ranges from 0.73 to 0.94. This indicates the spatial variations of all oceanic parameters during the three phases of ENSO are relatively constant from time to time. For example, the spatial distribution of mean chlorophyll-a relatively constant across the study areas regardless of the ENSO conditions which means the low, medium, and high values of the chlorophyll-a distribution are relatively constant from time to time (Figure 3).

In this study, Chlorophyll-a is only measured by its horizontal variability as the remote sensing satellite optimum to be observed. Figure 3 showed the number of chlorophyll-a is relatively higher constantly close to Kalimantan Island. We assumed this condition due to nutrient supply from several big rivers in Kalimantan such as Mahakam, Barito, and many more. The highest number of chlorophyll-a is not always describing a good water environment. It also indicates eutrophication which could impair the water itself (Wirasatriya, 2011). According to Bohlen and Boynton (1966) (Afdal; Riyono, 2007), the most ideal range for chlorophyll-a is not upper than 30 mg/m^3. Besides, it should be identified as eutrophication. Figure 3 showed that only in the La Nina phase the mean of chlorophyll-a is still in the range under 30 mg/m^3.



(a) La Nina (2010) (b) Neutral (2012) (c) El Nino (2015)

Figure 3. (a) chlorophyll-a during La Nina, (b) chlorophyll-a during Neutral Condition, (c) chlorophyll-a during El Nino. The classification used is the standard deviation to emphasize the spatial pattern of the low, medium, and high values in a certain period

4. CONCLUSIONS

The study evaluates the impact of several phases of ENSO to the four oceanic parameters which can be extracted free and directly from MODIS-Aqua through GEE using JavaScript command i.e. SST, NFLH, chlorophyll-a, and POC. All of these parameters play an important role in the marine environment. Based on a descriptive statistic from 471 sample pixels, those parameters are in a good range of environment index for marine creatures to live. Almost all of the parameters are dominantly affected by ENSO except chlorophyll-a and NFLH. Both of them are predicted to be affected by nutrient and water sediment which are not being studied in this paper. Also, the spatial variations of all oceanic parameters during the three phases of ENSO are relatively constant as we put on an example of chlorophyll-a in the study area. Further research should evaluate the effect of the ENSO phase not only on the oceanic parameters but also on the marine creatures which are very dependent on the water and/or food supply circumstances.

ACKNOWLEDGEMENTS

The authors would like to say thanks to NASA for providing free access to satellite imagery, NOAA Physical Science Laboratory to provide free access to ENSO data, and Google Earth Engine (GEE) for cloud computing of image processing freely.

REFERENCES

Afdal & Riyono, S. H. (2007). Kualitas Perairan Teluk Banten Pada Musim Timur. *33*(June 2005), 339–354.

Al Shehhi, M. R., Gherboudj, I., Zhao, J., Mezhoud, N., & Ghedira, H. (2013). Evaluating the performance of MODIS FLH ocean color algorithm in detecting the Harmful Algae Blooms in the Arabian Gulf and the Gulf of Oman. *OCEANS 2013 MTS/IEEE - San Diego: An Ocean in Common*, (November 2014).

Aryaguna, P. A. (2019). Habitat suitability mapping of rastrelliger brachysoma using MODIS image in WPP 711. *Indonesian Journal of Geography, 51*(2), 147–154. https://doi.org/10.22146/ijg.39919

Behrenfeld, M. J., Westberry, T. K., Boss, E. S., O'Malley, R. T., Siegel, D. A., Wiggert, J. D., … Mahowald, N. (2009). Satellite-detected fluorescence reveals global physiology of ocean phytoplankton. *Biogeosciences*, *6*(5), 779–794. https://doi.org/10.5194/bg-6-779-2009

Corvianawatie, C., Putri, M. R., Cahyarini, S. Y., Merpy, W., Oseanografi, P. S., Geoteknologi, P. P., … Laut, B. (2014). Variability of Sea Surface Temperature and Sea Surface Salinity in the Ambon Bay and its Relation to ENSO/IOD and Monsoon. *Indonesian Journal of Geospatial*, *3*(2), 1-8–8.

Gómez-Aguilar, J. F. (2020). Multiple attractors and periodicity on the Vallis model for El Niño/La Niña-Southern oscillation model. *Journal of Atmospheric and Solar-Terrestrial Physics*, *197*, 105172. https://doi.org/https://doi.org/10.1016/j.jastp.2019.105172

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, *202*, 18–27. https://doi.org/10.1016/J.RSE.2017.06.031

Jamshidi, S., & Bin Abu Bakar, N. (2011). A study on distribution of chlorophyll in the coastal waters of Anzali Port, south Caspian Sea. *Ocean Science Discussions*, *8*(1), 435–451. https://doi.org/10.5194/osd-8-435-2011

Koeshendrajana, S., Rusastra, I. W., & Martosubroto, P. (2019). Wilayah Pengelolaan Perikanan Negara Republik Indonesia (WPPNRI) 713: Gambaran Umum, Potensi dan Pemanfaatannya. In *Potensi Sumber Daya Kelautan dan Perikanan WPPNRI 713*.

Kementerian Lingkungan Hidup. (2014). *Keputusan Menteri Negara Lingkungan Hidup Nomor 51 Tahun 2004 Tentang Baku Mutu Air laut*. pp. 1–14.

Mohtar, A. T., Hughen, K. A., Goodkin, N. F., Streanga, I.-M., Ramos, R. D., Samanta, D., … Switzer, A. D. (2020). Coral-based proxy calibrations constrain ENSO-driven sea surface temperature and salinity gradients in the Western Pacific Warm Pool. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 110037. https://doi.org/https://doi.org/10.1016/j.palaeo.2020.110037

Racault, M.-F., Sathyendranath, S., Brewin, R. J. W., Raitsos, D. E., Jackson, T., & Platt, T. (2017). Impact of El Niño Variability on Oceanic Phytoplankton . *Frontiers in Marine Science* , Vol. 4, p. 133. Retrieved from https://www.frontiersin.org/article/10.3389/fmars.2017.00133

Sutton, P. J. H. (2018). Effects of Climate Change on Sea Levels and Inundation Relevant to the Pacific Islands. *Science Review*, 43–49. Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/4_Sea_Level_and_Inundation.pdf%0Ahttps://reliefweb.int/sites/reliefweb.int/files/resources/8_Seagrass.pdf

Wirasatriya, A. (2011). Pola Distribusi Klorofil-a dan Total Suspended Solid (TSS) di Teluk Toli Toli, Sulawesi. *Pola Distribusi Klorofil-a Dan Total Suspended Solid (TSS) Di Teluk Toli Toli, Sulawesi*, *1*(1), 10–12. https://doi.org/10.14710/buloma.v1i1.2990