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Analysis of Upwelling in the Southern Makassar Strait in 2015 Using Aqua-Modis Satellite Image

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Abstract: Because of the occurrence of upwelling during the eastern season, the waters to the south of Makassar Strait are a location that is relatively rich in organic materials. This study aimed to examine upwelling area development and distribution patterns in the southern Makassar Strait. This investigation employed sea surface temperature and chlorophyll-a data from the 2015 Level 3 Modis picture. The findings demonstrated that the southern Makassar Strait upwelling phenomena persist throughout the year, with the most substantial upwelling occurring in August and disappearing in October. A decrease in sea surface temperature and an increase in chlorophyll-a content were indicators of an upwelling. The upwelling begins in the southern Makassar strait and spreads to the southwest, according to wind speed and direction analysis.

Keywords: Upwelling, Makassar Strait, Chlorophyll-a, Sea Surface Temperature

1. Introduction

Indonesia's sea area is larger than its land area. The sea area covers two-thirds of the land area. The sea is a moving medium, both above and below the surface, which causes water circulation on both a small and large. Climate is a global factor that can alter the movement and distribution of water masses and the ocean's physical, chemical, and biological properties. Climate is primarily formed by differences in solar energy received by the earth's surface, resulting in temperature and air pressure variations. The wind may move from high to low-pressure regions due to the difference in air pressure. Differences in air pressure also affect rainfall that falls into the sea and humidity, which results in modifications to or differences in characteristics between regions with high and low rainfall [1].

South Makassar Strait, located in South Sulawesi (2-8^{o}S and 116-122°E), is well-known for its abundant marine wealth and fishery resources. The area includes the Makassar Strait, Java Sea, and the Flores Sea. In May, Makassar Strait is covered by warm sea surface temperatures (SST) around 29-30^{o}C and the concentration of Chlorophyll-a (Chl-a) is typically low (~0.3 mg.m^{-3}). In August, however, the concentration of Chl-a increased to a maximum of 1.3 mg m^{-3} [2]. Surface water in Makassar Strait typically has the highest temperature and lowest salinity from December to March, while temperatures are low and salinity is high from June to November [3]. During the South Heat Monsoon (SEM), Makassar's high salinity water surface is pushed into the Java Sea [4]. From May to August, the southeast wind blows steadily with a gradual increase in wind speed, and the pseudo-wind moves parallel to Sulawesi Island's southern coastline [5]. This situation caused an upwelling event, which resulted in an abundance of fish and other marine life in this area. Upwelling is an increase in deep-sea water mass (between 100 and 200 meters deep) at the surface (up to the euphotic layer) due to various factors. One of the factors is current divergence, in which the wind blows parallel to the coast or at the equator, pushing the water mass away from the coast [6]. The Coriolis force causes the surface water mass to migrate away from the coast, which leads to coastal upwelling. The water mass below the surface will fill the space left by the surface water mass due to the surface water mass moving away from the coast.

Upwelling was observed in several Indonesian seas, including one south of the Makassar Strait. Because the area has a high fishery potential, data on the upwelling location benefits the fisheries sector. In fisheries, the sea surface temperature variability can be used to determine the upwelling location. In contrast, the variability of chlorophyll-a concentration can be used to determine the fertility level of the waters.

Remote sensing is a powerful instrument for extracting water quality data and solving the problem of performing water quality monitoring [7]. The mapping of the upwelling area is done by identifying the variability of sea surface temperature and chlorophyll-a concentrations. It can be done using remote sensing data because it has a broader area coverage than direct checks in the field and can also be done regularly. Although the wavelength used in remote sensing imagery is sensitive to changes and differences in sea surface temperature and chlorophyll-a concentrations, it cannot penetrate clouds. The unavailability of continuous and complete data can be impacted because the research location is in the tropics, where cloud cover is very high. A monthly level 3 aqua MODIS (Moderate-Resolution Imaging Spectroradiometer) image was used as the data source. It is aimed that a comprehensive map of the entire research area will be possible.

2. Methodology

2.1. Study Methods

This study utilizes sea surface temperature (SST) and chlorophyll-a data from Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) satellite imagery level 3 with a monthly composite of 4 km resolution. The research time frame is one year, from January 2015 to December 2015, corresponding to four seasons. SeaDAS is used to evaluate the downloaded .nc formatted (netCDF) picture data. Microsoft Word, Excel, and SeaDAS 7.2 software are the tools employed in this study.

The Aqua MODIS satellite image is occasionally obscured by clouds, depending on the circumstances. As a result, the downloaded satellite image is first processed through cloud masking using SeaDAS to enter a formula that prevents the cloud value from being read as the sea surface temperature value. If the cloud masking process is not used, the resulting data is irrelevant and does not match the expected sea surface temperature value.

Processing at SeaDAS continues with image cropping based on the intended research area, then exporting the cropped data into a readable image format. The study area was chosen to examine the upwelling south of the Makassar Strait.

2.2. Data

The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire publication, and not as an independent document. Please do not revise any of the current designations.

2.2.1. Sea Surface Temperature (SST)

Sea Surface Temperature (SST) is an essential factor in the life of oceanic organisms since it affects their metabolic activity and reproduction. SST is also used to determine the quality of a body of water. Mapping of sea surface temperature is done with the help of satellites [8].

Temperature is the heat produced by collisions between molecules in an object. The higher the frequency of collisions, the higher the object's temperature. *Sea surface temperature* is defined as the average temperature in a warm and homogeneous surface layer between 0 and 70 meters, or what is known as mixed layer depth (MLD) [9]. The intensity of sunlight is the most crucial factor influencing sea surface temperature [10]. Wind, surface ocean currents, and the freezing and melting of polar ice are all factors that influence the distribution of sea surface temperature [11]. Surface current patterns, upwelling, divergence and convergence, turbulence, and global current circulation influence sea surface temperature [12]. The sea surface temperature in Indonesia ranges from 26 to 290°C [13]. Indonesia's high sea surface temperature is caused by the country's geographical location in the equatorial region, which receives heat energy from the sun all year.

2.2.2. Chlorophyll-a

The primary factor influencing photosynthesis is chlorophyll. Photosynthesis uses sunlight to convert inorganic compounds (CO_2 and H_2O) into organic compounds (carbohydrates) and O_2. Chlorophyll-a ($C_55H_72O_5N_4Mg$), which is dark green, and chlorophyll-b ($C_55H_72O_5N_4Mg$), which is light green, are found in higher plants. Chlorophylls a and b absorb the reddest light (600-700 nm) and the least of green light (500-600 nm).

The nitrate-rich layer and the biologically active process are used to determine the depth of the nitracline, which represents the lowest boundary of the layer where nitrate is assumed to be very limited using an isopleth of 1.0 M/l [14]. The isopleth depth is also related to the maximum chlorophyll-a depth (Deep Chlorophyll Maximum/DCM), which is related to a temperature range of 26 to 27°C [15].

The contribution of GI from DCM removal is calculated using the percent value of the variance of phytoplankton fluorescence at a depth of integration of the MODIS optical depth zone [16].

3. Results and Discussion

3.1. Distribution Pattern of Sea Surface Temperature (SST)

The processed MODIS level 3 satellite imagery in Figure 1 shows a different SST distribution pattern each month in the southern part of the Makassar Strait's Southern Waters. However, while the pattern varies by month, the temperature variability in Makassar Strait waters is not extreme, and the values appear relatively homogeneous. The visible temperature range is 26-31°C. SST distribution pattern in the southern part of the Makassar Strait in December-February (west season) shows a relatively high-temperature distribution in the range of 29-31°C. This relatively high-temperature range is still visible in March and April (transition season I). As the east monsoon season began in May, a temperature drop started to appear in the southern part of the Makassar Strait. This decline became more noticeable in June and July, indicating the beginnings of upwelling. This phenomenon becomes more visible in July and August, with a stratified temperature distribution pattern across the Makassar Strait's southern part.

Compared to the east monsoon, the distribution of SST values in September-October (transitional season II) shows that the indications of upwelling are weakening, as indicated by a decrease in the area of upwelling and an increase in SST values in the southern part of the Makassar Strait. In general, the east monsoon upwelling phenomenon and transition II exhibit a spatial pattern of SST distribution beginning in the southern part of Sulawesi Island and extending to the Flores Sea. From 2°C to 26.52°C, the SST range shrank significantly.

The upwelling in 2015 began in June in the southern part of the Makassar Strait and peaked in August. In August, there was a widespread increase in sea surface temperatures with low values, indicating that the upwelling distribution area peaked and expanded.

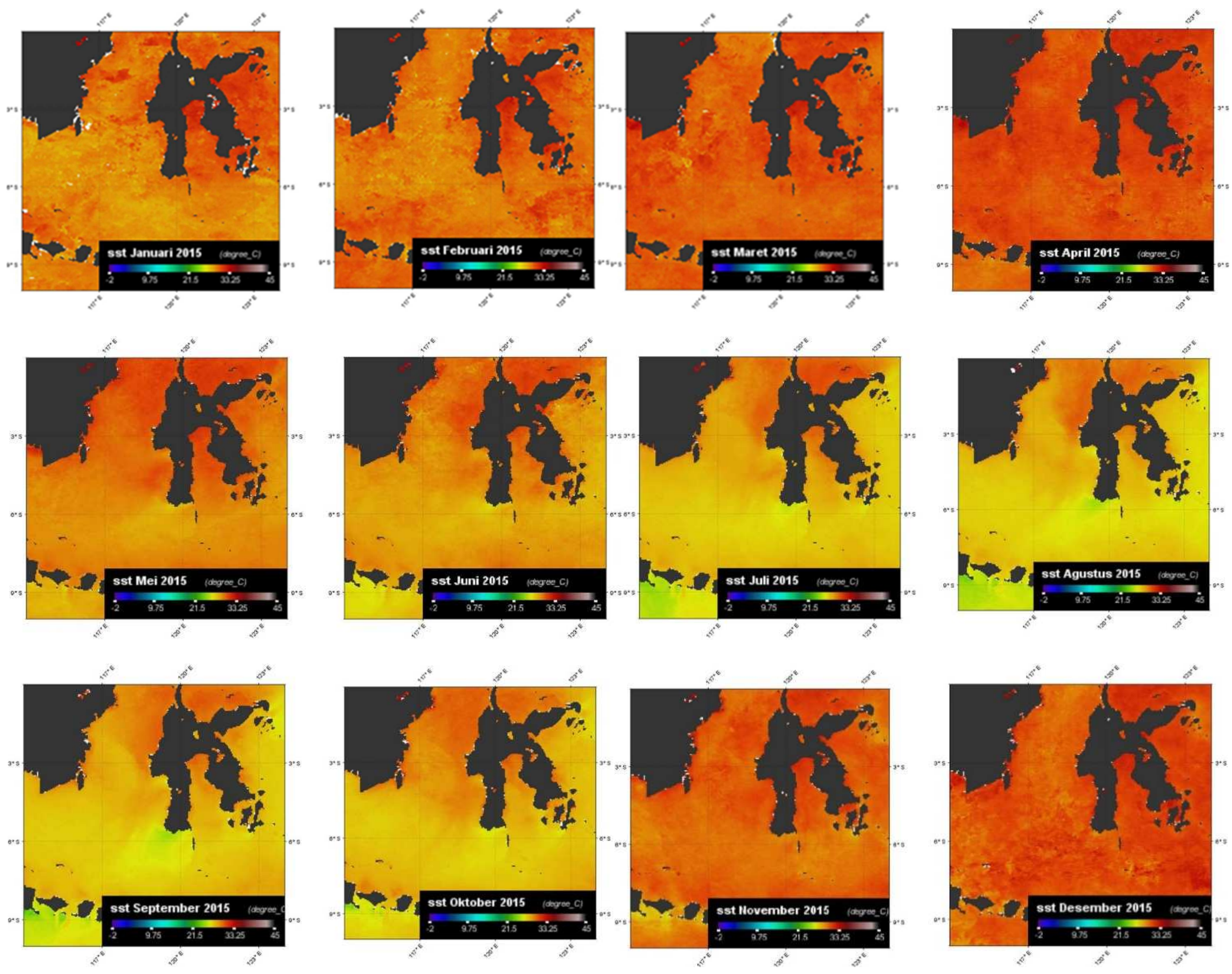

Figure 1. *SST spatial distribution pattern in the southern waters of the Makassar Strait in 2015.*

3.2. Distribution Pattern of Chlorophyll-a

The level of chlorophyll-a concentration varies according to season. During the east monsoon, which lasts from November to February, chlorophyll-a concentration in the Makassar Strait is lower than in other seasons. However, coastal areas have relatively high concentrations. It is most likely due to the influence of nutrient input from the land caused by the season's relatively high rainfall. The spatial distribution pattern of chlorophyll-a concentrations is similar to that of the west monsoon from April to May (transitional season I).

Based on the spatial distribution of chlorophyll-a concentrations during the east monsoon period (May-August), it is clear that there were no visible signs of an increase in chlorophyll-a concentrations in the southern part of the Makassar Strait at the start of the east monsoon in May. The concentration of chlorophyll-a increased, with a relatively high-level beginning in June and peaking in August. The high chlorophyll-a concentration in the east monsoon period that low SST preceded indicated upwelling. It is consistent with the findings of Wyrtki [17] and Illahude [18], who discovered that upwelling in this area occurred during the east monsoon, from June to August. The spatial upwelling pattern was still visible at the start of September's second transitional season. The appearance of the chlorophyll concentration, which began to decline again at the end of the second transitional season, suggests that the upwelling phenomenon will end at the end of the second transitional season (October).

In June, the distribution pattern of relatively high chlorophyll-a concentrations was still seen around the coastal areas, particularly the southern part of the Makassar Strait. In contrast, in July-August, the distribution pattern began to spread to the southwest of the island of Sulawesi towards the Flores Sea with high levels of chlorophyll concentration. ranged from 0.8-1.2 mg/m^3.

The temporal distribution of chlorophyll-a in the southern Makassar Strait in 2015 revealed that the increase in chlorophyll concentration began in June when the chlorophyll-a concentration started to rise in the range of 0.8-0.9 mg/m^3 and peaked in August and September when the value of chlorophyll-a concentration exceeded 1.0 mg/m^3. The widespread distribution pattern of chlorophyll-a in the southern part of the Makassar Strait demonstrates the increase in concentration.

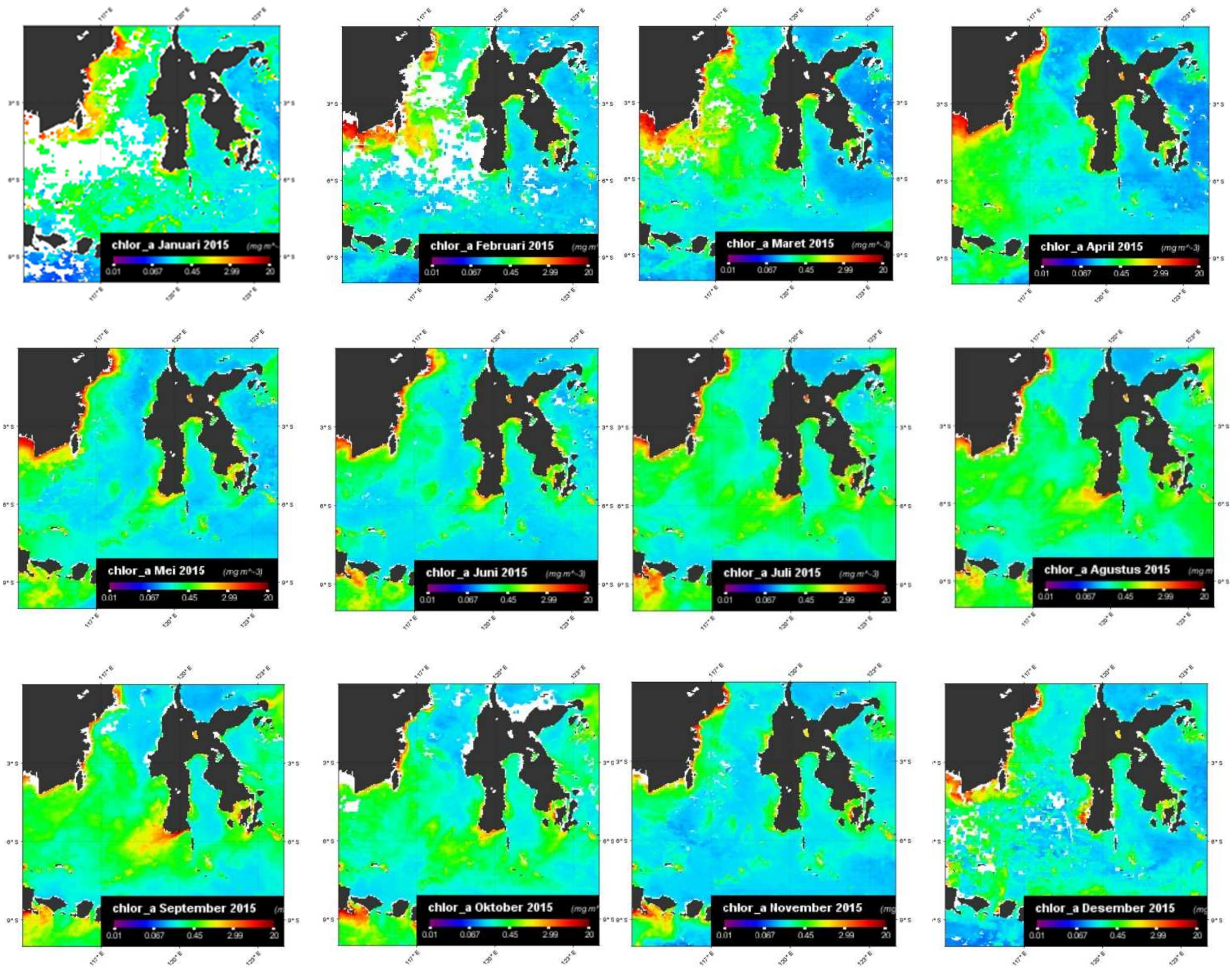

Figure 2. *Spatial distribution pattern of Chlorophyll-a in the southern part of the southern waters of the Makassar Strait in 2015.*

3.3. Upwelling Fluctuations Comparison of Literature Study Results

Inaku [19] conducted previous research in 2015, using MODIS level 1 imagery with a resolution of 1 km in HDF (Hierarchical Data Format) format. SST and Chlorophyll-a distribution data are daily for two years (2009-2010). The data in this study were processed by downloading SST images and chlorophyll-a MODIS Level 1 Makassar Strait Sea. The Modis Project software is then used to crop the existing image. The cut area is between 01° 00'00" and 07° 50'07" South Latitude and 114° 27'96" and 120° 47'35" East Longitude. Modis Browser software is used to process the results, and the desired output is ASCII data (*.asc) containing longitude, latitude, estimated sea surface temperature (SST), and chlorophyll-a variables.

Figure 3 depicts the distribution pattern of Chlorophyll-a in the southern part of the Makassar Strait based on processed MODIS level 1 satellite imagery.

The comparison of SST and chlorophyll-a distribution patterns for 2010 and 2015 shows that SST formation begins in June on average. An increase followed this decrease in SST in chlorophyll-a concentration, which spreads in the waters of the Makassar Strait's southern end. SST formation in 2010 started in the second week of June, peaked in the second week of August, and finished in the second week of October. SST formation occurred in the second week of June, followed by an increase in chlorophyll-a concentrations in the fourth week of June, which peaked in the fourth week of August and ended in the fourth week of September. The 2010 phenomenon was very similar to the 2015 phenomenon. SST formation in 2015 began in June, peaked in August, and ended in October. SST formation in June was followed by an increase in chlorophyll-a concentrations in June, which then increased in August and ended in September. Based on the analysis of the temperature and chlorophyll-a distribution patterns, it is seen that the peak of the upwelling phenomenon for 2015 occurred in August, as indicated by the decrease in SST in this result, which is not significantly different from the distribution pattern of SST and chlorophyll-a for 2010.

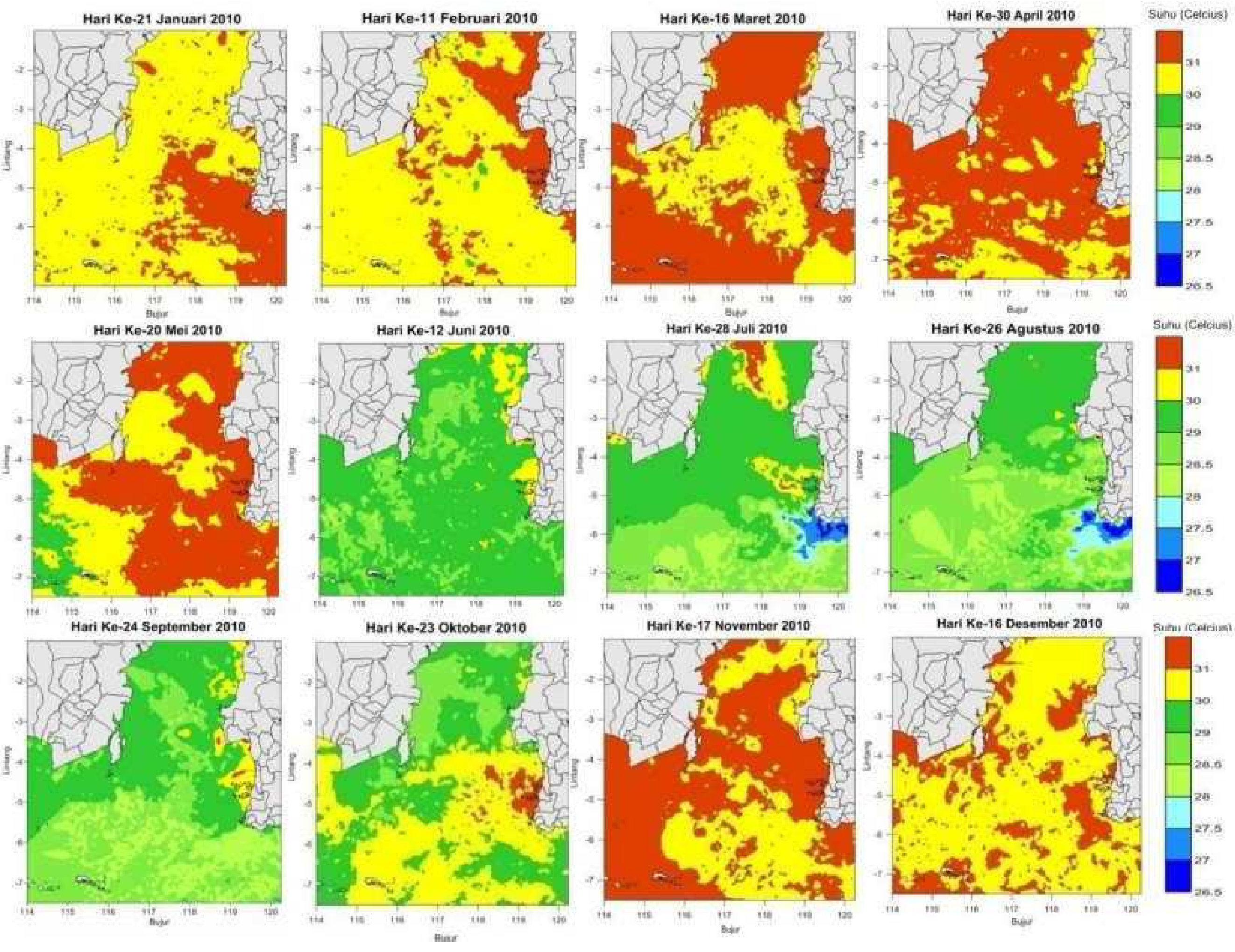

Figure 3. *Spatial distribution pattern of Chlorophyll-a in the southern part of Makassar Strait in 2010 (Source: Inaku, 2015).*

When the upwelling peaked in August, the pattern of upwelling spread could be seen toward the southwest of

Sulawesi Island. A drop in SST and an increase in chlorophyll-a concentration coincided with the upwelling distribution region expanding. Similar to 2015, there has been a rise in the overall region that was identified as an upwelling area with a southwesterly distribution pattern.

3.4. Factors Affecting the Occurrence of Upwelling

In August 2015, the MAJEFLOX expedition traveled to Makassar-Java-Flores. The expedition discussed the Arlindo Scheme and the Java Monsoon Current, where August 2015 was a strong El Nino year with maximum upwelling. Results of MAJAFLOX, 2015 processing measurements for atmospheric pressure, wind speed, and ocean cross-over speed south of the Makassar Strait in Banggai Maluku in January and August 2015.

Wand movement patterns in Indonesia generally follow the movement of the seasons. The wind moves in a different direction during each season. The wind pattern in 2015 shows that the wind shifted from the west and northwest with an average speed of 2.2 m/s in the south of the Makassar Strait during the west season (December-February). The wind movement pattern in the east monsoon (May-August) moves from the southeast at a faster average speed of 4.12 m/s.

The southeast monsoon wind direction, which was then supported by the movement of the mass flow of water from north to south of the Makassar Strait, caused Ekman Transport to move to the southwest (away from the south coast of Sulawesi). It caused a void of seawater masses on the surface, filled with seawater masses from the depths to achieve balance on the water surface. Upwelling occurs due to this process, bringing more nutrients, higher salinity, and lower seawater temperatures.

Depicts the results of MEJAFLOX's 2015 CTD measurement data processing in the south of the Makassar Strait in Banggai Maluku in August 2015 for temperature and salinity to depth. Upulled properties from about 60 m to the surface, indicating that the upwelling phenomenon occurs at that depth. The isotherm line of 25°C, isohaline 34.5 psu, and isopycnal 23 kg/m^3 are used in the upwelling phenomenon to indicate the presence of a cold-water mass lifted to the surface, thereby raising the mass of water containing a lot of chlorophyll marked in the image. Spatial distribution of SST and the vertical temperature distribution in Makassar Strait. As a result, the peak of the southeast monsoon conditions in the observation area occurred in August 2015, and upwelling events occurred in the area. The temperature difference of nearly 3.00°C became a strong indicator of water mass transfer from the water column to the surface. The southeast monsoon wind, which passed through the observation surface area and caused mass transport of water away from the coast, was the most influential factor in this event [21].

Simulations of upwelling in the south Makassar Strait. The model revealed that the upwelling mechanism was primarily related to the Southeast Monsoon, which was completely developed by MAJEFLOX between June and August. Strong winds caused vertical diffusivity during this season. The intensity of the wind pressure increased heat loss through heat flux, resulting in strong vertical mixing. The ITF in the Makassar Strait contributed to the mechanism of upwelling. The ITF caused recirculation and formation of a vortex, which caused convergence on the ITF pathway and divergence in coastal areas. The Selayar Strait in the south of Sulawesi Island serves as the outlet for this recirculation, with a portion of the current diverted to the Flores Sea. According to the study, minors played a role in reducing the intensity of upwelling, meanwhile, the topographical complexity caused ITF recirculation [21].

4. Conclusion

According to the study's findings, the distribution of SST values in the south of the Makassar Strait during the east monsoon was higher than in the west monsoon, with an average of 26.5-31.2°C. The low value of SST during the east monsoon period (May-August) was followed by an increase in chlorophyll-a concentration, indicating upwelling to the south of the Makassar Strait. The pattern of upwelling spread in the east monsoon began in June 2015, peaked in August, and ended in October, with the peak of upwelling occurring in August of that year, which was a strong El Nino year. The spatial distribution pattern of SST and chlorophyll-a concentrations in the southern waters of the Makassar Strait during the east monsoon also shows that the distribution pattern shifts to the southwest. Temperature, salinity, and density were exposed on the surface at the center of upwelling, where upwelled properties are from a depth of about 60 m to the surface with upwelling indicators, namely isotherm 25°C, isohaline 34.5 psu, and isopycnal 23 kg/m^3.

References

[1] Nontji, A. (2005). Archipelago Sea. Anugerah Nontji. Jakarta. Djambatan. Thurman.

[2] Setiawan, R. Y., & Kawamura, H. (2010). Summertime phytoplankton bloom in the South Sulawesi Sea. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *4* (1), 241-244.

[3] Susanto, R. D., Ffield, A., Gordon, A. L., & Adi, T. R. (2012). Variability of Indonesian throughflow within Makassar Strait, 2004–2009. *Journal of Geophysical Research: Oceans*, *117* (C9).

[4] Atmadipoera, A., Molcard, R., Madec, G., Wijffels, S., Sprintall, J., Koch-Larrouy, A., ... & Supangat, A. (2009). Characteristics and variability of the Indonesian throughflow water at the outflow straits. *Deep Sea Research Part I: Oceanographic Research Papers*, *56* (11), 1942-1954.

[5] Habibi, A., Setiawan, R. Y., & Zuhdy, A. Y. (2010). Wind-driven coastal upwelling along the South of Sulawesi Island. *ILMU KELAUTAN: Indonesian Journal of Marine Sciences*, *15* (2), 113-118.

[6] Leach, H. (1992). Introductory oceanography, by HV Thurman, Macmillan, New York, 1991. No. of pages: 526. Price:£ 29.50 (hardback). ISBN 067521317 7.

[7] Setiawan F, Subehi L, Matsushita B. (2021). Long-term change of water clarity in Lake Limboto derived from landsat data. IOP Conf. Series: Earth and Environmental Science 789 (2021) 012035, doi: 10.1088/1755-1315/789/1/012035.

[8] Anggreyni, A. D. R., Muljo, B., & Jaelani, L. M. (2011). Study of Changes in Sea Surface Temperature (SST) Using Aqua MODIS. Satellite.

[9] Nontji, A. (1993). Laut Nusantara [The Archipelago Sea]. Djambatan. Jakarta.

[10] Hastenrath, S. (1988). Prediction of Indian monsoon rainfall: further exploration. Journal of climate, 1 (3), 298-304.

[11] Welden, N. A., & Lusher, A. L. (2017). Impacts of changing ocean circulation on the distribution of marine microplastic litter. Integrated environmental assessment and management, 13 (3), 483-487.

[12] Sverdrup, H. U., & Munk, W. H. (1946). Empirical and theoretical relations between wind, sea, and swell. Eos, Transactions American Geophysical Union, 27 (6), 823-827.

[13] Kerimov, V. Y., Gordadze, G. N., Mustaev, R. N., & Bondarev, A. V. (2018). Based on the geochemical studies and modeling, formation conditions of hydrocarbon systems on the Sakhalin shelf of the sea of okhotsk. Oriental Journal of Chemistry, 34 (2), 934.

[14] Le Bouteiller, A., Blanchot, J., & Rodier, M. (1992). Size distribution patterns of phytoplankton in the western Pacific: towards a generalization for the tropical open ocean. Deep Sea Research Part A. Oceanographic Research Papers, 39 (5), 805-823.

[15] Mackey, D. J., Parslow, J., Higgins, H. W., Griffiths, F. B., & O'Sullivan, J. E. (1995). Plankton productivity and biomass in the western equatorial Pacific: biological and physical controls. Deep Sea Research Part II: Topical Studies in Oceanography, 42 (2-3), 499-533.

[16] Sarianto, D. (2018). Analisis Daerah Penangkapan Ikan Cakalang (Katsuwonus pelamis) di Sekitar Bacan dan Obi, Halmahera Selatan. SEMAH Jurnal Pengelolaan Sumberdaya Perairan, 2 (3).

[17] Wyrtki, K. (1961). Physical oceanography of the Southeast Asian waters (Vol. 2). University of California, Scripps Institution of Oceanography.

[18] Ilahude, A. G. (1978). On the factors affecting the productivity of the southern Makassar Strait. Marine Research in Indonesia, 21, 81-107.

[19] Inaku, D. F. (2015). Analisis pola sebaran dan perkembangan area upwelling di bagian selatan Selat Makassar. *Jurnal Administrasi dan Kebijakan Kesehatan Indonesia*, *25* (2), 105533.

[20] Utama, F. G., Atmadipoera, A. S., Purba, M., Sudjono, E. H., & Zuraida, R. (2017). Analysis of upwelling event in Southern Makassar Strait. In IOP Conference Series: Earth and Environmental Science (Vol. 54, No. 1, p. 012085). IOP Publishing.

[21] Atmadipoera, A. S., & Widyastuti, P. (2014). A numerical modeling study on upwelling mechanism in southern Makassar Strait. Jurnal Ilmu dan Teknologi Kelautan Tropis, 6 (2).