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# Analysis of Oil Spill Distribution in Bintan Utara Waters Using Sentinel-1A Satellite Imagery

# Analisis Persebaran Tumpahan Minyak pada Perairan Bintan Utara dengan Menggunakan Citra Satelit Sentinel-1A

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## ABSTRACT

Oil spills are a significant concern in the waters surrounding Bintan, Indonesia primarily due to tankers releasing ballast water before anchoring at the nearby port of Singapore, particularly during the north wind season. The region's high cloud cover presents challenges for detection efforts. However, the utilization of Sentinel-1 Satellite imagery offers a promising solution. This study aims to analyze the spatial distribution of oil spills in North Bintan waters using data collected from the Sentinel-1A satellite between December 2023 and January 2024. The study area includes Semelur Hamlet in Berakit Village, Bintan Regency. The analysis of data consists of oil spill detection and oil content. The results that the wind speed was measured within the range of 2 - 3.8 m/s, while the current speed fell within the range of 0.12 - 0.24 m/s. Additionally, the oil content was found to be less than 1 mg/l. The analysis conducted on the acquisition of December 6 - 24, 2023 revealed the presence of oil spills in four distinct areas. The spill areas were measured to be 1109 $m^2$, 346 $m^2$, 4258 $m^2$, and 1491 $m^2$, respectively. The windrose diagram reveals that the prevailing wind originates from the north northwest, accounting for 16% of the total wind occurrences. The average wind speed within this direction ranges from 3.6 - 5.7 m/s. Notably, the highest wind speed recorded exceeds 11.1 m/s and is observed to come from the north. The relationship between the process of image acquisition and the windrose diagram elucidates the impact of wind on the dynamics of oil spill movement.

**Keywords: Detection, North wind season, Oil content, Semelur Hamlet, Wind speed**

## ABSTRAK

Tumpahan minyak merupakan masalah yang signifikan di perairan sekitar Bintan, Indonesia yang disebabkan oleh pembuangan air *ballast* dari kapal-kapal *tanker* sebelum berlabuh di pelabuhan terdekat di Singapura, khususnya selama musim angin utara. Tingginya tutupan awan di wilayah ini menghadirkan tantangan bagi upaya deteksi. Namun, pemanfaatan citra Satelit Sentinel-1 menawarkan solusi yang menjanjikan. Penelitian ini bertujuan untuk menganalisis distribusi spasial tumpahan minyak di perairan Bintan Utara dengan menggunakan data yang dikumpulkan dari satelit Sentinel-1A antara bulan Desember 2023 dan Januari 2024. Wilayah studi meliputi Dusun Semelur di Desa Berakit, Kabupaten Bintan. Analisis data terdiri dari deteksi tumpahan minyak dan kandungan minyak. Hasilnya, kecepatan angin yang terukur berada pada kisaran 2 - 3,8 m/s, sedangkan kecepatan arus berada pada kisaran 0,12 - 0,24 m/s. Selain itu, kandungan minyak ditemukan kurang dari 1 mg/L. Analisis yang dilakukan pada akuisisi tanggal 6 – 24 Desember 2023 menunjukkan adanya tumpahan minyak di empat area yang berbeda. Area tumpahan minyak tersebut masing-masing seluas 1109 $m^2$, 346 $m^2$, 4258 $m^2$, dan 1491 $m^2$. Diagram *windrose* menunjukkan bahwa angin yang berlaku berasal dari barat laut utara, menyumbang 16% dari total kejadian angin. Kecepatan angin rata-rata dalam arah ini berkisar antara 3,6 - 5,7 m/detik. Khususnya, kecepatan angin tertinggi yang tercatat melebihi 11,1 m/s dan teramati berasal dari arah utara. Keterkaitan antara akuisisi citra dengan diagram *windrose* menerangkan bahwa angin memberikan pengaruh terhadap pergerakan tumpahan minyak.

**Kata Kunci: Deteksi, Musim angin utara, Kandungan minyak, Dusun Semelur, Kecepatan angin**

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## INTRODUCTION

Bintan Island has strategic waters in the Kepulauan Riau because it directly faces the South China Sea and Singapore Strait. These waters become shipping traffic from various countries. Potentially, there is a risk of oil spills originating from ships passing through the area (Irawan, 2017). Transfrontier pollution is a common factor in oil spills in the waters of Bintan Island. Transboundary pollution is also caused by ballast water illegally discharged by tankers entering Singapore. The discharge stems from regulation MPA No. 16 of 2008 Section 2 Paragraphs D and E, emphasizing that vessels entering Singapore must be physically clean (vessel and tank cleaning). Generally, ballast water discharged by ships contains oil and ship oil, which is classified as waste.

Seasonal factors affect the distribution of oil spills at sea. The season in question is the north wind season, which runs from October to February. The season occurs because the wind blows from the northern hemisphere to the southern hemisphere, directing winds and ocean currents toward the Kepulauan Riau (Karyoprawiro et al., 2019). Generally, the wind during this season blows with an average speed of 10-30 km/h, and wave height reaches 2.5 - 5 m (Negara, 2020).

Frequent oil spills in Bintan have damaged coastal areas, such as coral reefs, seagrass, and mangrove ecosystems (Abdullah et al., 2017). Ecosystem damage due to oil spills can cause the death of marine organisms, such as corals, reef fish, algae, and seagrass, breaking the marine food chain and reducing the productivity of primary waters to economic losses because it disrupts the livelihoods of people who depend on marine waters (Nukapothula et al., 2021). The waters surrounding Bintan Island are home to a diverse range of endangered habitats and biota. As a result, the government has taken significant measures to manage the area effectively by establishing dedicated conservation areas. According to the official document titled "Decree of the Minister of Marine and Fisheries (KKP) No. 18 of 2022," it has been determined that three distinct conservation areas have been established. These areas are identified explicitly as Teluk Sebong Waters, Gunung Kijang Waters, and Coastal Bintan Waters.

The Sentinel-1 satellite is one of the sensing vehicles that can support oil spill detection. The Sentinel-1 satellite has various advantages because it can operate without weather disturbances and penetrate clouds (Rijal et al., 2019). Then, it does not depend on day or night (Prastyani & Basith, 2019). The Indonesian region has high cloud cover, so using Sentinel-1 satellite imagery is appropriate in supporting the study of oil spill detection using satellite imagery. Based on this background, this study aims to analyze the spatial distribution of oil spills in North Bintan waters using data from the Sentinel-1A satellite image.

## MATERIALS AND METHOD

### Time and place of research

This study was conducted from December 2023 to January 2024. Sampling was conducted in Semelur Hamlet, Berakit Village, Teluk Sebong District, Bintan Regency (Figure 1). Furthermore, the samples were analyzed at the Laboratory of Sucofindo Indonesia Corp, Batam City.

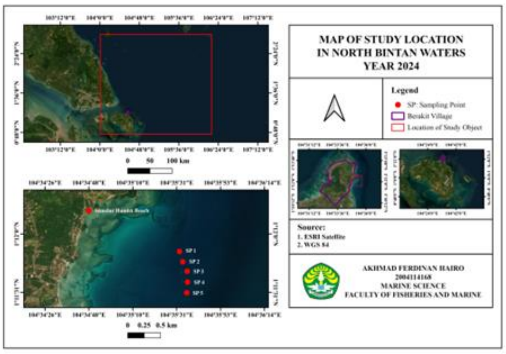


**Figure 1. Map of the study location**

### Methods

The research methodology employed in this study involves using a survey method. The data collection process encompassed measuring various environmental parameters, such as wind speed, ocean current speed, temperature, salinity, seawater pH, and the analysis of seawater samples to determine the oil content. The study focuses on the analysis of oil spill detection using satellite images. Specifically, the research employs the adaptive threshold method to identify and classify oil. Daily wind data was obtained from Meteorological, Climatological, and Geophysical Agency (BMKG) data. Oil content analysis in samples using the PO/LK/11 method.

**Sampling point determination**

The sampling was determined using a purposive sampling method along the waters of Semelur Hamlet, with sampling conducted at 5 points. The sampling point is 1.5 km from the coastline of Semelur Hamlet, with a distance of 160 m between each sampling point.

**Water quality**

Temperature was measured using a thermometer by dipping the lower end of the thermometer rod into the surface of the seawater. Then, it waited for 30 s, and the measurement results were recorded on a Celsius degree (°C) scale. Salinity was measured using a hand refractometer by opening the cover glass and cleaning it with distilled water. Then, the prism plate area was wiped with tissue in a direct direction. Next, seawater was taken using a drop pipette and dripped three times on the prism plate, and then the cover glass was closed. The salinity value was observed with a bright light lens so that the salinity value could be seen clearly. Finally, the observation results were recorded on a ppt (parts per thousand) or g/L scale.

pH is measured using a pH meter by dipping the pH meter sensor into the water collected in the container. Next, the number listed on the pH meter layer is recorded. Wind speed measurement using a digital anemometer by holding it vertically. The number of displays on the digital anemometer monitor is observed, and the results are recorded. Measure current velocity using a current drogue and stopwatch. The current drogue was placed on the sea surface, and observed its movement while being timed with a stopwatch. Next, the distance traveled from the current drogue is measured, and the travel time is recorded. The numbers obtained are entered into the equation (Manik et al., 2017):

$$v = \frac{s}{t}$$

Description: v = Current speed (m/s); s = Distance traveled (m); t = Time (s)

**Oil sampling in surface seawater**

Sampling was carried out in surface seawater using a 350 ml sample bottle. Then, the sample was dripped with three drops of $H_2SO_4$. Next, the sample bottle is labeled and put into an ice box filled with ice cubes. Finally, the sample is taken to the laboratory for oil content analysis (Nasution et al., 2016).

**Oil content analysis**

Oil content analysis was carried out in the laboratory using the PO/LK/11 method based on APHA (2017) guidelines. The parameters measured are oil and fat contained in the sample. The stages of sample analysis are as follows: the test sample is taken at as much as 200 mL and transferred into a separating funnel. The test sample bottle was rinsed with 20 mL of organic solvent and put into a separatory funnel. The separatory funnel is shaken for 2 minutes and left until the separation between organic solvent and water occurs. Next, the organic fraction layer was filtered from the water sample into a 100 mL volumetric flask using a funnel containing 11 cm filter paper and 1 g of anhydrous $Na_2SO_4$. The analysis results were read with the InfraCal TOG/TPH Analyzer formula in APHA (2017):

$$\text{TOG/TPH (mg/L)} = \frac{A \times B}{C}$$

Description: A= mg TOG/TPH determined from the standard curve; B= The volume of the sample after impounding; C = The volume of the sample after impounding

**Subset**

Subsets partition an image based on the specified region of interest (Rahayuningtyas & Jaelani, 2020). Processing a Sentinel-1 image scene will take a long time, with high hardware capabilities and large memory. According to the study location, a spatial subset is done with square or rectangular results.

**Speckle filtering**

Synthetic Aperture Radar images have a texture like sand and pepper called Speckles, which reduces image quality and makes interpretation of features in the image more difficult (Rahayuningtyas & Jaelani, 2020). In SNAP software, the available methods are mean, median, frost, lee, and gamma map. The Lee filter uses the MMSE (minimum mean square error) criterion by introducing local statistical values to the image. The Lee filter is used to reduce noise and, at the same time, preserve the edges. An adaptive filter is used to maintain the sharpness and detail of the image while reducing noise.

**Oil spill profile plot**

Visualization of oil spills that affect the reflection of SAR signals requires plotting the area by crossing the normal water area (bright area) and the area affected by the spill (dark spot). The comparison of the backscatter value (dB) between the bright area is 20 dB and the dark spot is 16 dB from the spill area plotting (Figure 2) and the value of the profile plot graph (Figure 3).

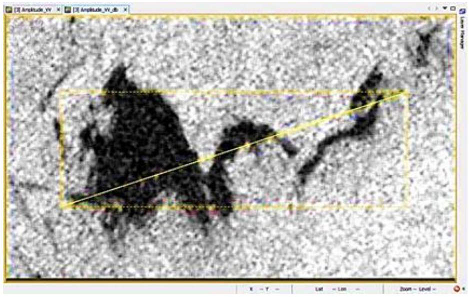

**Figure 2. Plotting of the spill area**

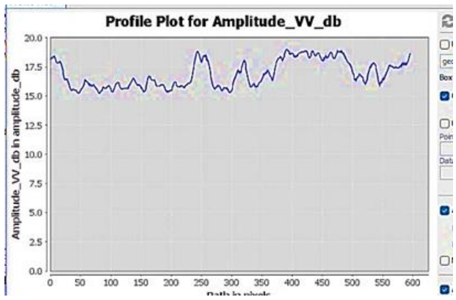


**Figure 3. Profile plot graph**

**Oil spill mapping**

In general, waters that oil spills have polluted will have lower pixel values or appear darker with a threshold difference of 3-4 dB or slightly lower than 4 dB used to extract pixels with oil spills (Rahayuningtyas & Jaelani, 2020). After determining the spill area from the previous process, masking can be done on the detected spot. Masking is helpful as a marker that the spot is an oil spill (Figure 4).

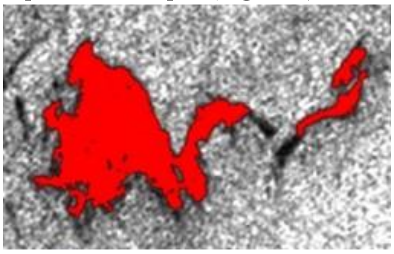

**Figure 4. Masking the spill area**

**Ellipsoid correction**

The image is inverted or not following the conditions in the field, so geometric correction is needed to match the position in the field (geometric correction) by applying the Ellipsoid Correction tool (Rahayuningtyas & Jaelani, 2020).

**Data visualization in QGIS**

Visualization in QGIS software serves as a data visualization and an extension of data analysis. The software has various tools that support processing oil spill data and measuring the spill area. In the software, data processing is carried out, such as identifying results, processing toolbox, extracting by expression, and dissolving for pixel value classification. Extract by expression and dissolve features are performed to determine the area of the detected oil spill.

**Windrose processing**

The data period used in this study starts from December 6, 2023, to January 6, 2024. Data is obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG) daily wind data. The data is processed into Microsoft Excel 2019 software. Furthermore, the data analyzed in the WRPLOT software will form a circular diagram that resembles a rose/cakra flower.

### Data analysis

Environmental quality parameters, including water quality parameters, wind speed and current data, and oil content data, are presented in tabular form. Each parameter will be explained descriptively. In addition, the results of oil spill detection and windrose data are presented as maps and diagrams. Both data are described descriptively to get an overview of the distribution of oil spills in North Bintan waters.

## RESULT AND DISCUSSION

### Measurement of environmental quality parameters

The measured environmental quality parameters include temperature, salinity, pH, wind speed and current, and oil content analysis. The following are the results of measuring water quality parameters, wind speed, and currents can be seen in Table 1.

Table 1. Water quality, wind speed, and current parameter data

| Parameters | Quality Standard Decree of the Minister of Environment (KLH) No. 51 Year 2004 | Water Quality Parameter Values | | | | |
|---|---|---|---|---|---|---|
| | | SP 1 | SP 2 | SP 3 | SP 4 | SP 5 |
| Temperature (°C) | Experience | 30 | 29 | 29 | 29 | 29,5 |
| Salinity (‰) | Experience | 27 | 29 | 31 | 29 | 29 |
| pH | 7 - 8,5 | 7,6 | 8 | 8,4 | 8 | 8 |
| Wind (m/s) | - | 3,8 | 2,2 | 3,3 | 3,1 | 2 |
| Current (m/s) | - | 0,24 | 0,14 | 0,21 | 0,19 | 0,12 |

Description: Natural is the normal condition of an environment, varying over time (day, night, and season).

Based on Table 1, the water quality parameters include the highest temperature found in SP 1 at 30°C and the lowest in SP 2 to SP 4 at 29°C. Furthermore, the highest salinity was found in SP 3 with a value of 31‰ and the lowest salinity in SP 1 with 27‰. Then, the highest pH was found in SP 3 with a value of 8.4, and the lowest in SP 1 with a value of 7.6. The results of wind speed measurements include the highest wind speed at SP 1 of 3.8 m/s and the lowest wind speed at SP 5 of 2 m/s. As for the current speed, the highest value was obtained in SP 1 at 0.24 m/s, and the lowest was in SP 5 at 0.12 m/s.

Based on the data from the measurement of water quality parameters, including temperature, salinity, and pH at the five sampling points, they showed compliance with the quality standards because they did not exceed the threshold values determined by the Decree of the Minister of Environment (KLH) No. 51 of 2004. Factors affecting differences in temperature, salinity, and pH values at each sampling point may include variations in measurement time, depth, and weather conditions when measurements are taken. These measurements were taken in the afternoon with sunny weather conditions.

According to Yolanda (2023), a relationship exists between temperature, salinity, and pH in waters. The relationship between salinity and temperature is that when the water temperature decreases, the salinity also tends to decrease because cold water only holds a little salt. Furthermore, the relationship between salinity and pH is that water with high salinity levels usually has a higher pH because salt can act as a buffer and balance acid or base levels. Then, the relationship between temperature and pH lies in the ability of temperature to increase the rate of chemical reactions in water, including acid-base, so that when water temperature increases, the pH of water also tends to increase.

Table 2. Oil content analysis data

| Sample Identification | Parameters | Unit | Results | Maximum Standard |
|---|---|---|---|---|
| Seawater SP1 | Oils and Grease | mg/L | < 1,00 | 1,00 |
| Seawater SP 2 | Oils and Grease | mg/L | < 1,00 | 1,00 |
| Seawater SP 3 | Oils and Grease | mg/L | < 1,00 | 1,00 |
| Seawater SP 4 | Oils and Grease | mg/L | < 1,00 | 1,00 |
| Seawater SP 5 | Oils and Grease | mg/L | < 1,00 | 1,00 |

Description: (<) less than the indicated detection limit.

Based on the results of current speed measurements, there are variations at each sampling point. Differences in wind speed cause this during measurements at different locations. The data collected shows that the average ocean current speed is directly proportional to the wind speed blowing at that time, and the direction of the current is also influenced by the current wind direction, where the direction of the wind blowing determines the direction of the current. This statement aligns with Rifai (2020), who states that seasonal changes in wind direction and speed in ocean waters affect the direction and speed of ocean surface currents. The results of the five samples contain oil with numbers below 1 mg/L of the maximum standard.

**Oil spill detection**

Detection of oil spills from images includes coordinates, number, and area of oil spills. The following is a collection of images of detection results that can be seen in Figure 5 to Figure 10

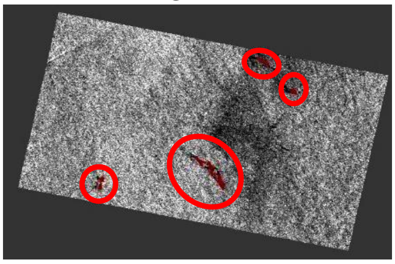

**Figure 5. Period December 6, 2023**

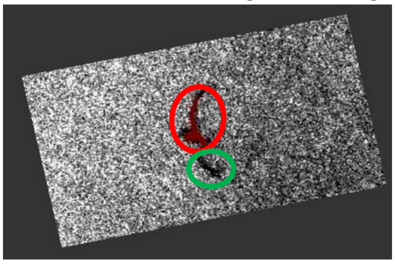

**Figure 6. Period December 12, 2023**

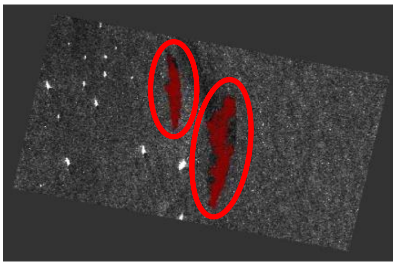

**Figure 7. Period December 18, 2023**

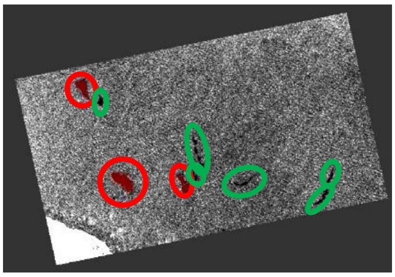

**Figure 8. Period December 24, 2023**

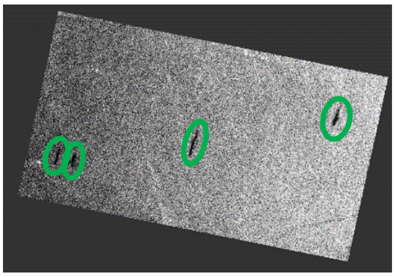

**Figure 9. Period December 30, 2023**

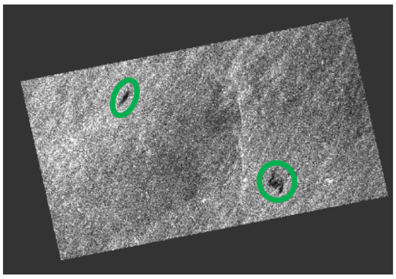

**Figure 10. Period January 6, 2024**

Based on the analysis from Figure 5 to Figure 10, red spots were detected as oil spills marked with red circles, while the surrounding black spots were identified as look-alike marked with green circles. Figure 5 shows four red spots with a total area of 1109 $m^2$ at the coordinates 104°49'1" E - 1°34'59" N, located in the Natuna Sea. Figure 6 shows one red spot with a total area of 346 $m^2$ at coordinates 104°50'26" E - 1°47'19" N and one black spot near and in the Natuna Sea. Figure 7 shows two red spots with a total area of 4258 $m^2$ at coordinates 104°45'5" E - 1°43'35" N, located in the Natuna Sea. Figure 8 shows three red spots with a total area of 1491 $m^2$ at coordinates 104°37'9" E - 1°11'49" N and six black spots between the waters of Semelur Hamlet and Malang Rapat Village. The distance from the coast of Semelur Hamlet to the spill area is 4.42 km. Figure 9 shows four black spots at coordinates 104°50'31" E - 1°24'58" N. Figure 10 shows two black spots at coordinates 104°30'13" E - 1°37'48" N, both located in the Natuna Sea. To clarify the position of the detection results, the overlay is shown in Figure 11, and the map layout is shown in Figure 12.

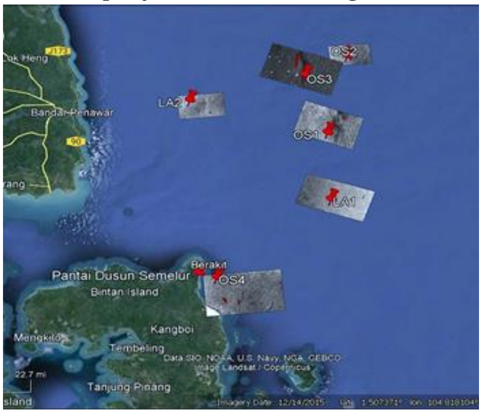


**Figure 11. Overlay of detection results**

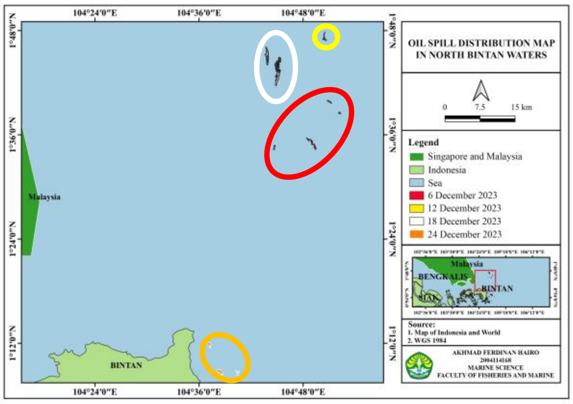


**Figure 12. Map of oil spill detection results**

Based on Figure 11, OS is an oil spill, and LA is a look-alike. The order of images from OS 1 to OS 4 follows the order of image acquisition, as do the images of LA 1 and LA 2. Meanwhile, Figure 12 shows the position of the spill based on the time of occurrence. The difference in spill area over time has been identified as caused by oil plumes mixing with other oil plume sources. Wind-driven currents play a significant role in the variation of oil spill area and dispersion over time. According to Millah et al. (2019), wind-driven ocean currents contribute to variations in oil spill displacement and changes in oil thickness over time.

The oil spill movement observed in the satellite images acquired on 6, 12, 18, and 24 December 2023 was caused by oil plumes dissolving in the sea due to wind, currents, or the source of the oil spill around the area. According to Siagian et al. (2016), wind and tidal currents move elements of the oil layer relative to each other and accelerate the dispersion process. In this study, tidal factors are not considered, and surface ocean currents are assumed to be influenced only by wind. The wind is one of the factors for the current generation (Jewlaika et al., 2014). According to Alfajri et al. (2017), wind provides about 2% of its speed to surface currents, so wind becomes a factor in surface current generation.

The appearance of oil spill plumes in the image cannot be confirmed whether it is from the source of the oil spill in the first image acquisition. Due to dynamic physical factors in highly dynamic waters, oil spills at sea are difficult to predict and confirm directly in the field (Faristyawan et al., 2023). Over time, the concentration of the plume decreased when it reached the waters of Semelur Hamlet. This is supported by the analytical data listed in Table 2, which shows that all five samples contain oil in concentrations below 1 mg/L. According to Rosiana et al. (2019), spreading oil causes the layer to become thinner, and the rate of oil evaporation increases.

When samples were analyzed, the concentration of oil plumes reaching the coast of Semelur Hamlet showed low concentrations (less than 1 mg/L) (Table 2). Based on this study's oil content analysis method, the detection limit set is 1 mg/L. Therefore, the concentration of oil detected in the waters of Semelur Hamlet containing oil is still below the threshold and is considered harmful to marine biota. Following the provisions of the quality standard in Decree of the Minister of Environment (KLH) No. 51 of 2004, the concentration of oil in the sea that can harm marine biota is 1 mg/L.

### Windrose data processing

The following windrose processing results can be observed in Figure 13.

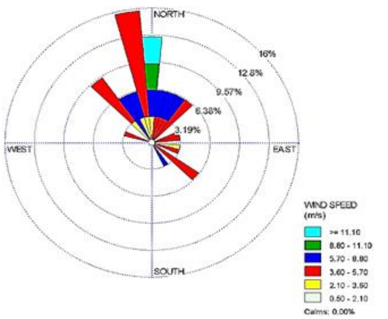


**Figure 13. Windrose diagram for the period December 6, 2023 - January 6, 2024**

Figure 13 explains that the wind is dominated from the north-northwest direction by 16% with an average speed of 3.6 - 5.7 m/s. Then, blowing from the north at the highest wind speed of > 11.1 m/s. Wind conditions indicate that the wind blowing in Bintan waters is influenced by the north wind season. Quoted from the website Meteorological, Climatological, and Geophysical Agency (BMKG) Tanjung Pinang Meteorological Station, the weather system of the north wind season or the beginning of the north/northeast monsoon (wet phase), namely the monsoon surge/north wind strengthens and brings wet air masses that produce moderate-heavy rain with strong winds (10 - 20 knots, maximum can reach 30 knots) and can last a long time, if there is a Borneo vortex, usually occurs in December - January. Sampling was conducted in the afternoon on 6 January 2024, and weather conditions were cloudy. Based on information from the Meteorological, Climatological, and Geophysical Agency (BMKG) Tanjung Pinang Meteorological Station Bulletin (2024), on 6 January 2024, stated that weather conditions on Bintan Island experienced light rain.

Based on news from Harian Kepri (2024), oil waste was found in the waters of Malang Rapat Village, Gunung Kijang District, on February 23, 2024. Winarto, a mangrove observer and chairman of the Bintan Tourism Village Communication Forum, argues that the waste pollutes the beach, affects fishermen who want to go to sea, disturbs the comfort of tourists, and is very dangerous for marine and coastal ecosystems. Sugeng Riyono, Head of Tanjunguban PLP Base, said the waste was frozen. His party worked with the Bintan Environmental Agency, Bintan Satpolairud, and TNI and involved the Malang Rapat Village community in handling the oil waste. The following is the appearance of black oil waste that pollutes the waters of Malang Rapat Village, which can be seen in Figure 14.

**Figure 14. Black oil waste polluting the waters of Malang Rapat Village**

The studies assumed that the possible waste was caused by the influence of the oil spill movement from the acquisition of 6 - 24 December 2023. The waste reached the waters of Malang Rapat Village because currents influenced by north winds carried it. This assumption is reinforced by information from the Meteorological, Climatological, and Geophysical Agency (BMKG) and the windrose diagram that has been presented. Malang Rapat Village is located slightly jutting eastwards from Semelur Hamlet. The village is adjacent to Semelur Hamlet. In addition, wind movements tend to head south because they are influenced by the north wind season. This assumption is in line with the study conducted by Damayanti et al. (2022), which found that wind affects the movement of oil spills and tends to move according to the direction of wind movement.

## CONCLUSION

This study concludes that oil spills were detected in acquisitions 6, 12, 18, and 24 December 2023 with an area of 1109 $m^2$, 346 $m^2$, 4258 $m^2$, and 1491 $m^2$, respectively. Most of the spills occurred in the Natuna Sea, except for the spill on the 24 December 2023 acquisition located between Semelur Hamlet and Malang Rapat Village. Wind factors play an important role in the movement of oil spills and changes in oil thickness.

## REFERENCES


**[APHA] American Public Health Association.,** 2017. *Standard methods for the examination of water and wastewater (23rd ed.)*. Washington DC.

**[BMKG] Badan Meteorologi Klimatologi dan Geofisika Stasiun Meteorologi Tanjung Pinang.** Iklim Pulau Bintan. Diakses pada 3 Maret 2024 di laman *web* https://stamet-tanjungpinang.bmkg.go.id/iklim-pulau-bintan/.

**[BMKG] Badan Meteorologi Klimatologi dan Geofisika Stasiun Meteorologi Tanjung Pinang.,** 2024. *Buletin Meteorologi Stasiun Meteorologi Raja Haji Fisabilillah Tanjungpinang Periode Februari 2024*. Tanjung Pinang. p19.

**[KKP] Kementerian Kelautan dan Perikanan.,** 2022. *Keputusan Menteri Kelautan dan Perikanan Republik Indonesia Nomor 18 Tahun 2022 tentang Kawasan Konservasi di Perairan di Wilayah Timur Pulau Bintan Provinsi Kepulauan Riau*. Jakarta.

**[KLH] Kementerian Lingkungan Hidup.,** 2004. *Keputusan Menteri Negara Lingkungan Hidup Nomor 51 Tahun 2004 Tentang Baku Mutu Air Laut*. Jakarta.

**[MPA] Maritime and Port Authority of Singapore.,** 2008. *Post Marine Circular: Procedures to Control Tank Cleaning and Disposal of Sludge and Slop*. Port Marine Circular.

**Abdullah, A., Nurrachmi, I., Nedi, S.,** 2017. Analisis kandungan minyak air laut dan kelimpahan diatom di perairan pesisir Pantai Sakera Kabupaten Bintan Provinsi Kepulauan Riau. *Jurnal Online Mahasiswa*, 4(1): 1-13.

**Alfajri, A., Mubarak, M., Mulyadi, A.,** 2017. Analisis spasial dan temporal sebaran suhu permukaan laut di Perairan Sumatera Barat. *Dinamika Lingkungan Indonesia*, 4(1): 65-74.

**Damayanti, F.N., Putra, I.D.N.N., Nuarsa, I.W., Hartuti, M.,** 2022. Deteksi pola sebaran tumpahan minyak (oil spill) menggunakan Citra Sentinel-1A di Perairan Karawang. *Journal of Marine and Aquatic Sciences*, 8(2): 210-220.

**Faristyawan, R., Wicaksono, P., Arjasakusuma, S., Wardani, R.,** 2023. Identifikasi tumpahan minyak di laut akibat tank cleaning menggunakan metode tidak terselia. *Jurnal Kelautan Nasional*, 18(1): 69-78.

**Harian Kepri.,** 2024. Limbah minyak cemari Perairan Bintan, nelayan tak bisa melaut. Diakses pada 5 April 2024 melalui https://www.hariankepri.com/limbah-minyak-cemari-perairan-bintan-nelayan-tak-bisa-melaut/.

**Irawan, S.,** 2017. Kondisi hidro-oseanografi perairan Pulau Bintan (Studi Kasus Perairan Teluk Sasah). *Jurnal Kelautan*, 10(1): 41-53.

**Jewlaika, L., Mubarak, M., Nurrachmi, I.,** 2014. Studi padatan tersuspensi di perairan Pulau Topang Kabupaten Kepulauan Meranti Provinsi Riau. *Jurnal Perikanan dan Kelautan*, 19(1): 53-66.

**Karyoprawiro, B L., Wahyuningtyas, E.M., Siahaan, V.R.,** 2019. Zona lokasi labuh jangkar dan pencucian kapal dalam upaya pengurangan transboundary marine pollution di Selat Malaka. *Sociae Polites*, 20(2): 115-126.

**Manik, Y., Nedi, S., Elizal, E.,** 2017. Analisis fraksi sedimen dan bahan organik di perairan muara Sungai Dumai Provinsi Riau. *Jurnal Online Mahasiswa*, 4(2): 1-9.

**Millah, N., Anggriani, I., Nugraheni, K.,** 2019. Simulasi pergerakan tumpahan minyak di laut dengan pengaruh angin. *SPECTA Journal of Technology*, 3(3): 11-19.

**Nasution, N.A., Siregar, Y.I., Nurachmi, I.,** 2016. Hubungan kandungan minyak dengan kelimpahan diatom pada strata kedalaman di perairan Tanjung Buton Kabupaten Siak. *Jurnal Online Mahasiswa*, 3(2): 1-11.

**Negara, G.S.,** 2020. Dampak lingkungan terhadap pencemaran laut di pesisir utara Pulau Bintan selama musim angin utara. *Jurnal Saintek Maritime*, 20(2): 137-144.

**Nukapothula, S., Wu, J., Chen, C.,** 2021. Potential impact of the extensive oil spill on primary productivity in the Red Sea waters. *Continental Shelf Research*, 222, 104437.

**Prastyani, R., Basith, A.,** 2019. Deteksi tumpahan minyak di Selat Makassar dengan penginderaan jauh sensor aktif dan pasif. *Jurnal Elipsoida*, 2(1): 88- 94.

**Rahayuningtyas, N., Jaelani, L.M.,** 2020. Analisis deteksi tumpahan minyak di perairan Pantura Jawa menggunakan satelit Sentinel-1A metode *adaptive threshold*. *Jurnal Teknik ITS*, 9(2): 55-60.

**Rifai, A., Rochaddi, B., Fadika, U., Marwoto, J., Setiyono, H.,** 2020. Kajian pengaruh angin musim terhadap sebaran suhu permukaan laut (Studi Kasus: Perairan Pangandaran Jawa Barat). *Indonesian Journal of Oceanography*, 2(1): 98-104.

**Rijal, S.S., Setyawan, F.O., Aliviyanti, D.,** 2019. Ground deformation mapping in Lombok earthquake 2018 using SAR (Synthetic Aperture RADAR) technology. *Correct IJJSS Conference 2019*. Bali.

**Rosiana, K., Amin, B., Efriyeldi, E.,** 2019. Analisis kandungan minyak pada sedimen dan hubungannya dengan kelimpahan makrozoobentos di perairan Sungai Pakning Kabupaten Bengkalis Provinsi Riau. *Jurnal Online Mahasiswa*, 6:1-12.

**Siagian, Y.S., Rifai, A., Ismanto, A.,** 2016. Pemodelan sebaran tumpahan minyak di perairan Teluk Balikpapan, Kalimantan Timur. *Jurnal Oseanografi*, 5(2): 270-276.

**Yolanda, Y.,** 2023. Analisa pengaruh suhu, salinitas dan pH terhadap kualitas air di muara perairan Belawan. *Jurnal Teknologi Lingkungan Lahan Basah*, 11(2): 329–337.