The Use of Active Remote Sensing Data and Adaptive Threshold Method for Analysing Oil Spill in West Side of Java Sea

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Abstract. Oil spill phenomena, particularly in the West Side of Java Sea, occur due to the dense oil industry and maritime activities causing potential vulnerability to oil pollution. Rapid detection of oil spill distribution needs to be conducted to minimize the resulting impacts. By developing an early detection method for oil spills in the Western Java Sea using Synthetic Aperture Radar (SAR) technology from Sentinel-1A Satellite using SNAP software with an Adaptive Threshold approach. The detection method is based on the principle that oil causes the sea surface to become calm, resulting in a drastic reduction in radar wave reflection values. Research results show oil spill detection in June 2023 with an area reaching 73,823 km² and an accuracy level of 93,75% based on confusion matrix validation. This research also integrates windfield analysis to support radar image interpretation, with wind speed estimation results of 1-12 m/s and dominant direction toward northwest to north. Windfield data was validated using BMKG reanalysis data and Copernicus Marine My Ocean Pro. The developed method is superior to optical imagery in terms of detection visualization and object classification capability within the spill area. The findings of this research provide important contributions to the development of effective monitoring and response systems to protect marine ecosystems, and can serve as a basis for planning environmental impact mitigation from oil spills in the region.

Keywords: Adaptive Threshold; Oil spill; Sentinel 1-A Satelite; Synthetic Aperture Radar (SAR); West Side of Java Sea

I. INTRODUCTION

The phenomenon of oil spills has become a major threat to the global maritime ecosystem, especially in areas with intensive upstream oil and gas industry activities. This phenomenon is particularly a serious concern in Indonesian waters, including the West Java Sea and the area around the East Coast of Lampung, which are oil and gas exploration and production zones with complex operations [1]. Operations located in offshore areas have challenges in terms of limited workspace and facilities, where all activities are centered on one operation deck, while other infrastructure such as pipelines are on the seabed with limited accessibility for routine maintenance [2]. This operational complexity increases the risk of oil spill incidents due to various factors, including lack of oversight of the integrity of subsea pipelines, suboptimal monitoring systems, and limited implementation of regular maintenance programs [3]. These conditions are also influenced by the dynamic characteristics of the maritime environment, where the movement of currents waves, and weather conditions can affect the difficulty of operating and maintaining subsea infrastructure [4]. Oil spills will have a serious impact on the environment and marine biota. Therefore, a fast and efficient method of detecting oil spills at sea is needed. This aims to provide spatial information in the early containment of oil spills. Handling this problem is a top priority given the high demand for compliance with ESG (Environmental, Social, and Governance) standards that affect the company's reputation and financial performance in the global competitive arena.

The development of remote sensing technology can open new insights in an effort to detect and monitor oil spills through the use of Synthetic Aperture Radar (SAR) systems. SAR image data acquired in June 2023 was processed using the Adaptive Threshold method that works with the principle of identifying low backscatter values as an indicator of the presence of oil spills. This method applies an algorithm that dynamically adjusts the threshold value based on the spatial characteristics of the image, enabling automatic and more accurate darkspot detection [6]. SAR technology has advantages in this detection due to its all-weather and all-time operational characteristics, independent of lighting conditions, weather and time of day, and the ability to penetrate the atmosphere strongly [7]. Sentinel-1A SAR developed by the European Space Agency (ESA) through the Copernicus Browser website provides data with optimal spatial resolution and adequate temporal coverage for oil spill detection needs [8].

SAR image data obtained from Sentinel-1A shows high sensitivity to changes in sea surface characteristics, where the presence of oil layers can be detected through the analysis of low backscatter values (dark spots) in radar images [9]. This phenomenon occurs because the oil layer causes a smoothing effect on the sea surface, which results in the reduction of radar backscatter and produces a signature that contrasts with normal sea surface characteristics [10]. Detection of dark areas using the Adaptive Threshold method. This method is done by applying the oil spill detection tools feature in the SNAP application. The implementation of a SAR-based detection system with the Adaptive Threshold method aims to develop a more effective oil spill monitoring mechanism in the waters of the West Java Sea. This process performs initial segmentation using the Adaptive Threshold technique, where the threshold value is determined dynamically based on the local characteristics of the image, rather than using a uniform threshold value for the entire image. The algorithm will distinguish between true oil spills and other look-alikes phenomena such as cloud shadow areas or upwelling using various geometric and radiometric features [11].

Wind field estimation is a crucial aspect in monitoring sea surface conditions using radar data. Backscatter analysis on radar images is significantly affected by wind conditions that form capillary or gravity waves on the sea surface. The conversion of backscatter values into wind speed estimates is done using the CMOD5 model developed by the European Center for Medium-Range Weather Forecasts (ECMWF) and implemented in SNAP software. This model has proven effective in producing accurate wind speed estimates based on satellite radar data [12]. The research shows that the accuracy of wind field estimation can reach 2 m/s in wind speed conditions between 2-20 m/s [13]. The wind speed and direction information obtained is very important for various applications, including oil spill prediction.

II. METHODOLOGY

2.1 Research Area

The research location in the Western Java Sea region (East Coast of Lampung) is shown in Fig. 1. The selection of the location is due to the oil spill case in June 2023 in the recording time on June 27, 2023 in the case study area within the following The coordinates of the study area are defined by four boundary points: Boundary 1 at 03°44'11" S, 105°59'33" E; Boundary 2 at 03°43'43" S, 106°30'20" E; Boundary 3 at 04°55'25" S, 105°56'47" E; and Boundary 4 at 04°54'03" S, 106°25'25" E.

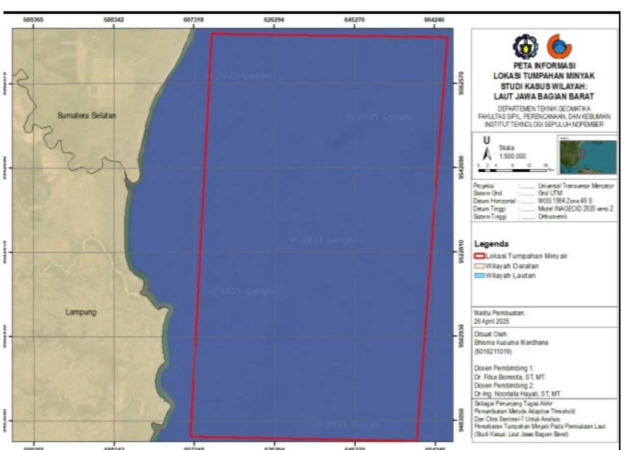

Figure 1. Research Location Information Map.

2.2 Data and Equipment Used

Data usage and software to hardware equipment for the final project as follows Laptop used in data processing and data acquisition. SNAP (Sentinel Application Platform) software with open source license for oil spill detection processing. Google Earth software to create Area of Interest of the study area. Google Collaboratory page to process validation data. Software for map creation and visualization. Microsoft Office 2019 software with ITS license for report generation.

The materials used for processing in this study are Sentinel-1A Satellite Image as a research data processing material by downloading images through the Copernicus Browser. with Level 1 Ground Range Multi Look Detected High (GRDH) type, Interferometric Wide Swath (IW) mode with dual polarization VV and VH. Image data acquired in June 2023. Additional data in the form of wind speed and direction data obtained by performing the Wind Field Estimation process in SNAP. Additional data in the form of wind speed and direction data obtained from BMKG and Copernicus Marine meteorological stations as supporting validation data.

2.3 Phase of Research Implementation

The flowchart in Fig. 2 illustrates the sequential steps of the study, from initial data collection to final analysis, providing a visual representation of the research methodology. The materials used for processing in this study are Sentinel-1A Satellite Image as a research data processing material by downloading images through the Copernicus Browser. with Level 1 Ground Range Multi Look Detected (GRD) type, Interferometric Wide Swath (IW) mode with dual polarization VV and VH. Image data acquired in June 2023. Additional data in the form of wind speed and direction data obtained by performing the Wind Field Estimation process in SNAP. Additional data in the form of wind speed and direction data obtained from BMKG and Copernicus Marine meteorological stations as supporting validation data.

The process of detecting oil spills through Sentinel-1 satellite data starts with obtaining imagery from platforms like Copernicus Browser. These platforms offer different data collection methods, including Interferometric Wide Swath (IW) mode, which should be selected based on the specific requirements of oil spill research.

Apply File orbit preprocessing step corrects SAR imagery from satellites like Sentinel-1 by aligning image data with the satellite's precise orbital path. This correction ensures accurate geographic positioning of each pixel, making sure image elements correspond to their correct Earth surface locations. Without proper orbital file application, significant spatial errors can occur, compromising the reliability of spatial analysis and change detection.

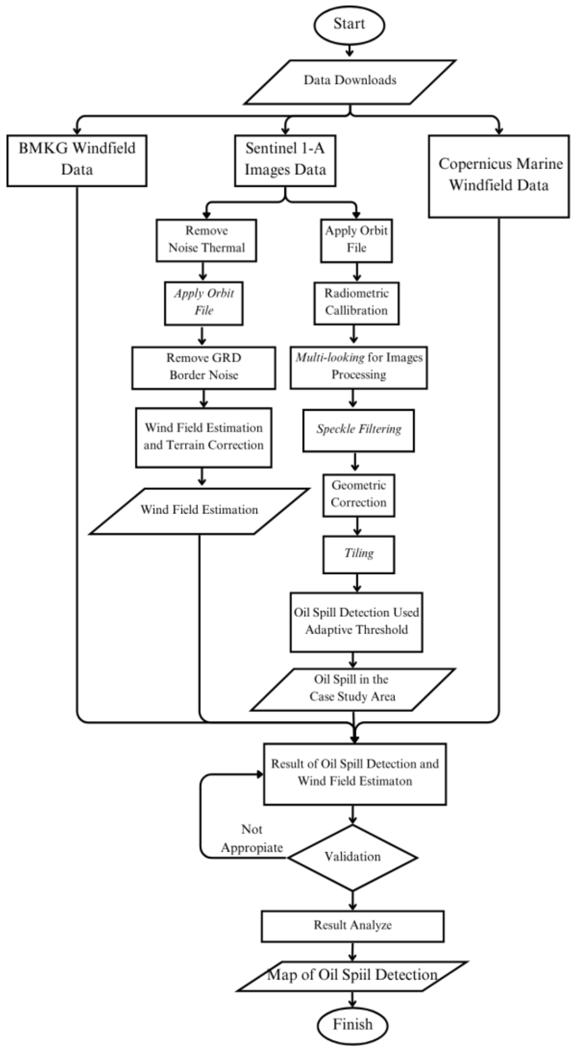

Figure 2. Flowchart of Data Processing.

Radiometric Calibration is the crucial processing step converts pixel values to accurate backscatter measurements. While uncalibrated SAR images work for qualitative analysis, calibration is essential for quantitative studies. The process uses sigma nought conversion to transform digital numbers into physical backscattering coefficients, which measure how effectively Earth's surface reflects radar energy back to the sensor.

SAR imaging often creates unbalanced pixel dimensions between azimuth and range directions when pursuing high resolution, leading to poor radiometric quality. Multi-looking addresses this by balancing pixel sizes in both directions to create nearly square geometry. Though this may reduce spatial resolution, it improves radiometric quality and minimizes initial speckle effects. SAR images contain sand-and-pepper-like texture called speckle, which degrades image quality and complicates feature interpretation. Various spatial filtering techniques can reduce speckle. The 7x7 Lee Sigma filter is commonly selected for its adaptive characteristics, ability to preserve important details like object boundaries, and effectiveness in speckle reduction while maintaining oil spill details.

This step corrects imagery orientation issues that may not match actual field conditions, such as inverted or misaligned images. Using SNAP's Range Doppler Terrain Correction feature, the geographic positioning is adjusted to ensure imagery accurately represents the observed area, which is essential for reliable analysis results.

Tiling supports adaptive thresholding by dividing images into smaller sections that better suit local conditions and pixel values, helping focus on target objects like oil spills. This technique also addresses memory constraints when processing large satellite images by enabling separate processing of smaller sections while maintaining original data quality.

Wind field analysis supports sea surface monitoring using radar data, as backscatter analysis is heavily influenced by wind conditions that create surface waves. The CMOD5 model from ECMWF, implemented in SNAP software, converts backscatter values into wind speed estimates with accuracy reaching 2 m/s for wind speeds between 2-20 m/s. This wind information is crucial for oil spill prediction applications.

Dark area identification uses Adaptive Threshold methodology through SNAP's oil spill detection tools. This technique performs initial segmentation using dynamically determined threshold values based on local image characteristics rather than uniform thresholds. The algorithm differentiates between actual oil spills and similar-looking phenomena like cloud shadows or upwelling using various geometric and radiometric features. This digital image processing stage extracts important information through gray level analysis, focusing on key parameters such as area coverage, total pixels, and standard deviation of dark regions. Area coverage indicates oil spill size changes over time, while standard deviation evaluates detection precision. Parameters like mean, variance, and texture help distinguish oil spills from other similar sea surface phenomena.

III. RESULT AND DISCUSSION

This research used data from Synthetic Aperture Radar (SAR) images of the Sentinel-1 satellite, which is part of the Copernicus program of the European Space Agency (ESA). One of them uses the Sentinel-1A satellite, which is equipped with a C-band radar instrument and is capable of recording data in various acquisition modes. The data used in this study was acquired in Interferometric Wide Swath (IW) mode with a spatial resolution of about 10 meters and includes two types of polarization, namely VV (Vertical Transmit, Vertical Receive) and VH (Vertical Transmit, Horizontal Receive). SAR image data was collected for the West Java Sea study area, on June 27, 2023 based on the events or phenomena observed. The data was downloaded through the Copernicus Open Access Hub platform in Level-1 Ground Range Detected High (GRDH) format, which has been calibrated and corrected in SNAP software through several stages.

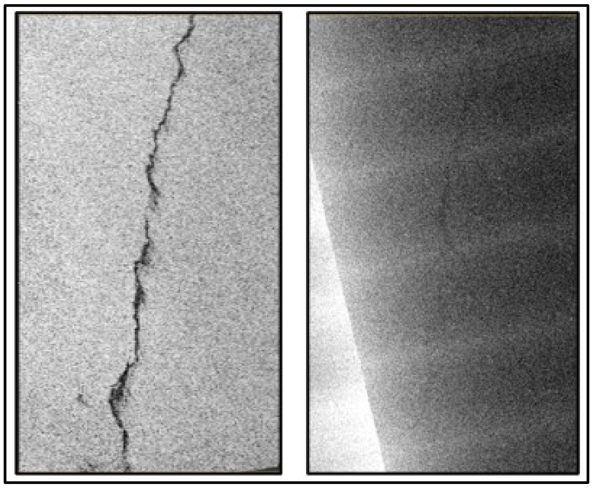

Figure 3. Visualization of Oil Spill Detection Results Polarization Mode: (1) VV polarization, (2) VH polarization.

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After pre-processing the Sentinel-1 image and segmenting it using the tiling method, the image was divided into six sections to facilitate the analysis of the spatial and backscatter intensity of the sea surface. Oil spill detection in SAR images is generally characterized by lower backscatter values compared to the surrounding area, as oil on the sea surface dampens capillary waves and blocks the reflection of radar waves back to the sensor (Fig. 3).

Analysis of the radar intensity in the six sections of the area shows variations in different sea surface characteristics (Fig. 4). Section 1 indicates strong reflectance, possibly normal waves or a surface without oil. Section 2 shows a lower maximum intensity, suggesting a smoother surface due to a thin oil layer. Section 3 has a variety of textures with a mix of clean and oil-indicated areas. Section 4 shows the widest range of intensities, indicating rough areas (wind/waves) and areas with potential oil spills. Section 5 has a similar distribution but with lower intensity peaks, implying a calmer surface, possibly due to oil. Finally, Section 6 is dominated by a smoother sea surface, which is typical of oil spills that dampen radar signals.

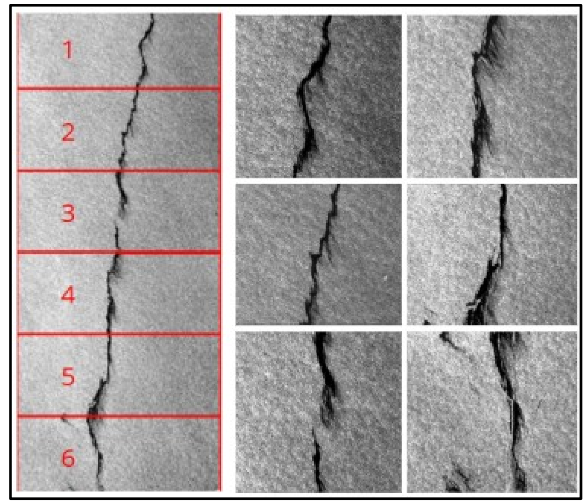

Figure 4. Segmentation of Oil Spill Detection Part Results.

Overall, this analysis provides an overview of the potential presence and characteristics of oil spills in different parts of the observed area. The histogram analysis of the VV channel SAR image in dB units aims to understand the distribution of radar backscatter intensity values in each subset area. This is important in the process of identifying objects or phenomena such as oil spills, as oil on the sea surface tends to reduce the roughness of the sea surface, resulting in lower backscatter values (darker on SAR images).

The image in Fig. 5 is a visualization of normalized pixels, representing image data in grayscale with pixel values ranging between 0 and 1. This scale is indicated by the colorbar on the right, where 0 (black) represents the minimum pixel value and 1 (white) represents the maximum pixel value. The image itself displays a prominent vertical linear pattern in white at the center of the black field. Visually, this white pattern resembles a line or crack that extends vertically along the image. This kind of visualization is common in digital image processing to highlight certain features or objects in the image through high contrast

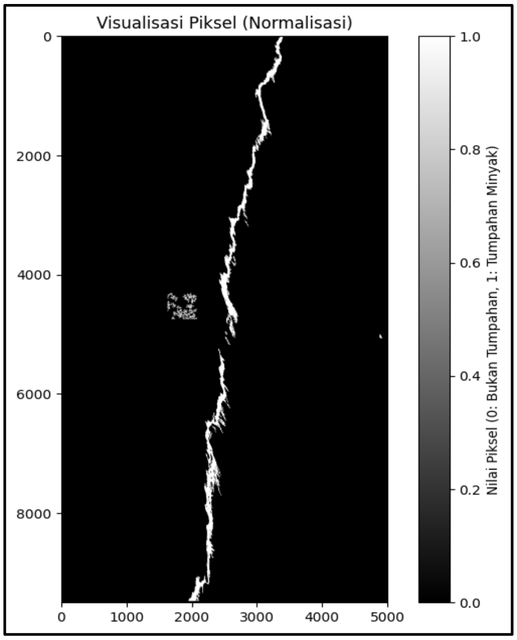

Figure 5. Visualization Result of Oil Spill Pixel Value from Masking Result.

In the context of oil spill detection, this white pattern can represent the area detected as an oil spill after image processing, while the black area is the surrounding seawater surface. Based on the classification results obtained, the area identified as Probable Oil Spill has an area of 73.823 km². The value in Table 1 shows the estimated sea area affected by the oil spill indication at the time of the image recording.

TABLE 1. CONFUSION MATRIX PROCESSING RESULTS FOR VALIDATION DATA.

Classification	Area (km²)
Probable Oil Spill	73.823 km²

In the process of oil spill detection using radar images, sometimes black areas appear that resemble oil spills but are not actual oil (Fig. 6) . Such areas are called lookalikes. In oil spill detection using radar imagery. Lookalikes is a term used to refer to features or areas on imagery that appear to resemble oil spills, but are not actually oil. Lookalikes have a dark appearance in radar imagery just like oil spills because they cause attenuation of small ocean waves (capillary waves), reducing the reflection of the radar signal (backscatter). As a result, the radar records the area as dark. One type of lookalikes that often appear are phytoplankton, which are microscopic organisms that live floating on the ocean surface.

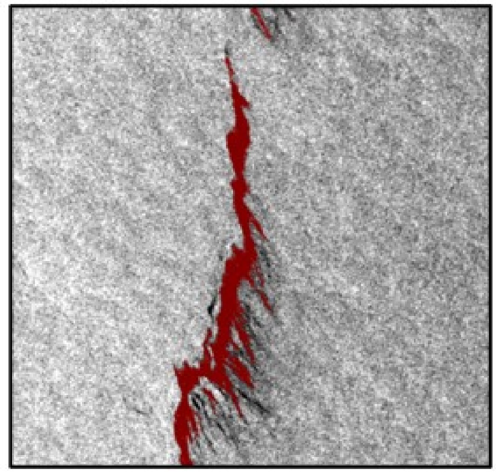

Figure 6. Visualization of Black-colored Lookalikes in Oil Spill Detection

To support the interpretation of oil spill detection, the direction and speed of sea surface winds were estimated using Wind Field Estimation available in ESA SNAP software (Fig. 7). This process utilizes backscatter data from the VV channel of Sentinel-1 imagery, which is correlated with empirical models such as CMOD5 to calculate surface wind vectors. This estimation provides spatial information on the distribution of the wind field at the time of image recording, which can then be used to assess whether the detected image anomalies are consistent with the oil dispersal pattern based on the wind direction. Thus, wind analysis serves as an additional verification to confirm the validity of oil spill detection from radar images.

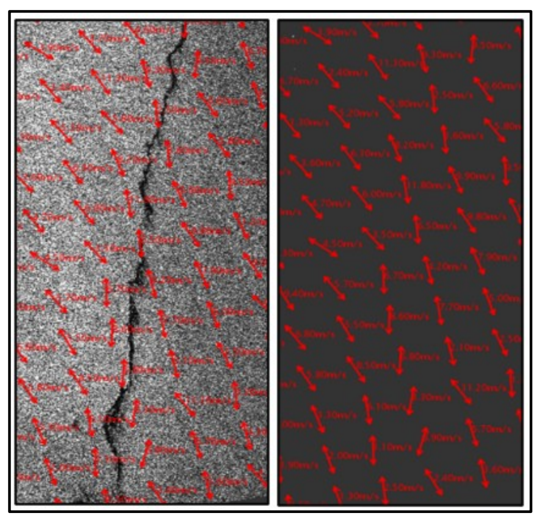

Figure 7. Visualization of Wind Direction and Speed Detection Results: (1) Satellite Image, (2) wind direction and speed vector results.

The analysis of oil spill data was conducted in six parts to gain a detailed understanding of pixel values in the detected spills, utilizing Sentinel-1A satellite imagery and wind speed data. A key finding was that the wind direction estimated by SNAP had a 180° ambiguity, necessitating a two-way arrow representation. Based on the analysis of wind speed and direction (heading) in the study area, a clear picture of atmospheric dynamics emerged. The majority of winds originated from the south to southeast (170° to 210° heading), indicating a dominant movement from south towards north or northeast, as confirmed by the concentration of headings in that sector. While some deviations from the north (around 330°–350° heading) were noted, wind speeds generally varied between 1.2 m/s and 11.8 m/s, with an average of 4–8 m/s, categorizing them as moderate winds. The highest speed recorded was 11.8 m/s (175.83° heading), and the lowest was 1.2 m/s (189.36° heading). This analysis suggests that the prevailing wind patterns, primarily from the south to northwest and north, could potentially propel oil spills towards the north or northeast from their sources.

This accuracy test was conducted for oil spill detection and for wind field estimation. In the oil spill detection validation test process. Validation of oil spill detection results is an important stage in remote sensing research that aims to evaluate the level of accuracy and reliability of the methods that have been developed. Confusion matrix is chosen as the main evaluation metric because of its ability to provide an overview of the classification by displaying the distribution of correct and incorrect predictions in the form of a matrix that is easy to interpret.

The model accuracy result of 93.75% indicates that most of the model matches the actual conditions in the field. This figure generally indicates a very good model performance in classifying samples, both oil spills and non-oil spills. The ground truth data used as a validation reference in this study was obtained through manual visual interpretation of the same Sentinel-1 image, given the limited access to in-situ field data that is ideally required for more objective validation.

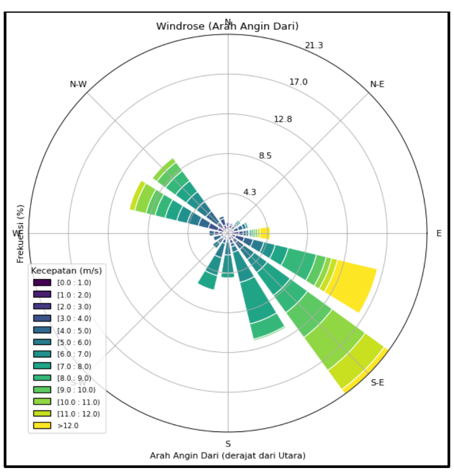

Figure 8. Visualization of BMKG wind speed and direction reanalysis data

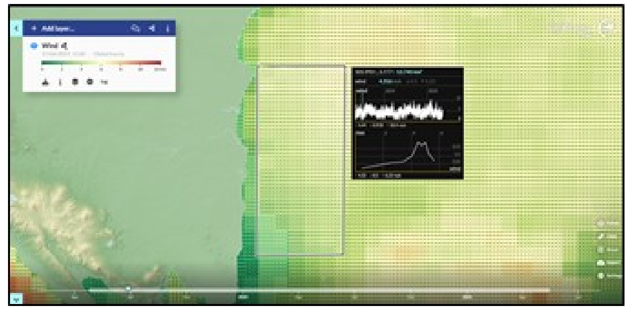

Figure 9. Visualization of Copernicus Marine My Ocean Pro wind speed and direction data.

Based on visual analysis of the processed data (Fig. 7) and validation data from BMKG (Fig. 8), and Copernicus Marine validation data (Fig. 9), there is a fairly strong agreement between the two, especially in terms of the range of wind speed and direction. The processed results show wind speeds ranging from 1.2 m/s to 11.8 m/s, reflecting wind characteristics of moderate to relatively low intensity. Data from BMKG shows a dominant wind speed distribution in the range of 1.0 m/s to 12.0 m/s, with the highest frequency in the Northwest (N-W) direction, as depicted in the wind rose. Data from Copernicus Marine My Ocean Pro, shows wind speeds ranging from 1.0 m/s to 10.8 m/s and has a dominant wind direction in the Northwest (N-W) direction. This correspondence in dominant direction shows that both the processed results and the BMKG and Copernicus Marine data describe similar regional wind circulation patterns. The similarity in the direction and range of wind speeds indicates that the model or method used in data processing is able to accurately represent wind conditions, and can be relied upon to support further analysis, such as modeling the distribution of oil spills at sea.

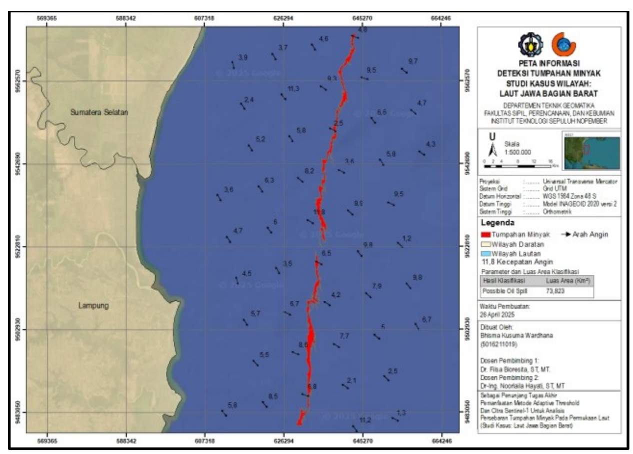

Figure 10. Oil Spill Site Identification Map and Windfield Estimation..

IV. CONCLUSION

This research discusses oil spill detection in the West Java Sea, an area vulnerable to oil pollution due to intensive maritime activities and the oil industry. Oil spills are a major concern due to their devastating impact on marine ecosystems and coastal communities. Therefore, fast and accurate detection of oil spills is crucial.

To address this issue, this research develops an effective early detection method. The method utilizes the Synthetic Aperture Radar (SAR) technology of the Sentinel-1A Satellite, which has the ability to detect oil spills under various weather conditions and time of day. SAR imagery was chosen due to its ability to operate in various weather and time conditions, as well as its wide area coverage. The Adaptive Threshold approach is used to identify areas that potentially contain oil spills based on the backscatter characteristics of SAR images.

The element of windfield estimation is given special emphasis in this study. Wind conditions at the sea surface have a significant influence on the backscatter analysis of radar images. Therefore, the estimation of wind speed and direction is crucial in understanding the dynamics of oil spill dispersion. The results of the windfield estimation achieved an accuracy of 2 m/s in wind speed conditions between 1-12 m/s. The results of this study show that the developed method is able to improve the accuracy of oil spill detection compared to optical images and is able to classify objects within the spill area. The information obtained from oil spill detection and windfield estimation is essential for effective response planning and environmental impact mitigation. Specifically, the study found that in June 2023, an oil spill was detected in the Western Java Sea with an area of 73,823 km². The findings are expected to form the basis for an effective monitoring and response system to protect marine ecosystems in the region.

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