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Oil Spill Detection to Protect The Marine Ecosystem in Karawang Waters

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Abstract

Indonesian waters frequently experience pollution from oil spills, such as the incident in Karawang Waters in July 2019, when oil and gas leaked from the YYA-1 well on the Offshore North West Java Block, owned by PT. Pertamina Hulu Energi resulted in marine pollution. Spatial detection of oil spill distribution is necessary to analyze the characteristics, extent, and direction of oil spread. Detection was carried out using remote-sensing radar technology that can penetrate clouds, with the adaptive threshold method for faster, more efficient detection. Sentinel-1A imagery with VV and VH polarization was used on July 18, August 11, September 16, and October 10, 2019. The detection results indicated that the oil spill spread westward from July to September, and was cleaned by October. Detection using VV polarization yielded better results than detection using VH polarization. In July, the extent of the oil spill reached 27.524 km² (VV polarization) and 19.521 km² (VH polarization). In August, the area decreased to 10.386 km² (VV polarization) and 8 km² (VH polarization). In September, the oil spill covered 3.277 km² (VV polarization) and 2.245 km² (VH polarization), while in October, no oil spill was detected.

Keywords : Sentinel-1A imagery; oil spill; adaptive threshold; VV and VH polarization, Karawang waters

1. Introduction

Oil spills in marine regions worldwide continue as oil drilling, production, and transportation activities persist. The extent of damage to local ecosystems and the effectiveness of different oil-spill response technologies are heavily influenced by environmental conditions [1]. Indonesia is a maritime nation and is also one of the top oil producers in Southeast Asia. This franchise entails safeguarding and managing the marine environment and addressing the threats posed by oil spills. Oil spills and oil drilling have historically impacted marine ecosystems and tourism, affecting the health of coastal communities [2][3]. Oil spills and marine ecosystem devastation from wells offshore Karawang, drilled in the last days of July 2019. Containment measures and the immediate removal of oil from the water were done by Pertamina Hulu Energi Offshore North West Java (PHE ONWJ), which was in charge of the well following the oil spill [4]. Karawang Regency's coastal waters serve a range of economic and social functions, including oil and gas Extraction, Capture fisheries, Aquaculture, Marine tourism, and Maritime Transport. This

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coastal area is affected by the spill's impact, and the oil spill and marine activities in this coastal area also impact a range of seawater in the area. Therefore, to mitigate the impact, seawater quality sampling is conducted in coastal waters and around river estuaries [5][6]. Oil spills have a profoundly negative impact on marine ecosystems and coastal environments. Remote sensing technology, such as Synthetic Aperture Radar (SAR), is widely used from satellites to detect and monitor oil spills on the sea surface [7]. Synthetic-aperture radar (SAR) imagery excels in Earth observation, even in adverse weather conditions. With microwaves, SAR can penetrate clouds and operate without sunlight. SAR satellites typically operate in low polar orbits [8]. Radar on SAR satellites can collect signals in vertical (V) and horizontal (H) polarizations. VH polarization is obtained from the V signal transmitted and received in H, while HH comes from the transmitted and received horizontally. SAR polarization modes include single, dual, and multi-polarization [9]. SAR imagery has various wavelengths called bands, such as L (390 – 1550) MHz, C (3.900 - 6.200) MHz, and X (6.200 - 10.900) MHz. SAR missions operating for earth observation include ALOS/PALSAR (2005, L band), TerraSAR-X (2007, X band), RADARSAT 3 (2009, C band), TanDEM-X (2010, X band), and Sentinel-1 (2014, C band) [10][11][12]. Sentinel-1 is widely used for oil spill detection in oceanography. Studies have shown that the C-band wavelength is most suitable for detecting oil layers, as it provides the maximum contrast [13]. This research uses Sentinel-1 wide-swath SAR to extract features that distinguish oil spills from moving ships from similar objects [14]. In Indonesia, Sentinel-1 has been used to observe oil spread on the sea surface in several oil spill events, such as the oil spill phenomenon in the Java Sea, including Karawang waters [15][16], the tragedy of the broken underwater oil pipeline in Balikpapan [17], and oil spill monitoring in shipping lanes in the Makassar Strait [18].

PT Pertamina engages in offshore oil drilling in the northern regions of Karawang, which comes with a high risk of oil spills that impact marine life and coastal communities, as well as oil and gas drilling in the relevant offshore waters [19]. The overriding aim of this study is to examine the oil spills that occurred in the vicinity of the Karawang Coastal Waters between September and October of 2019, the result of the identified oil and gas leaks from the YYA-1 well in the Offshore North West Java (ONWJ) Block, which PT Pertamina Hulu Energi also operates. Certain aspects of the oil spills and the processed monitoring of the oil diagnostic tools Spatial Distribution and the oil spill from the Coastal Waters of Karawang do help in providing essential tools for the impact of the environmental spill, as well as strengthening the remote sensing and image processing tools for the oil spill that determine the environmental impact of the oil spill and the value of oil spill to the Comprehensive coastal Management to support and the planned structured tools for the oil spill and the value of coastal Management.

2. Methods

2.1. Research location

The study was conducted in an area polluted due to an oil leak from the YYA-1 oil well on the Offshore North West Java (ONWJ) Block, which belongs to PT. Pertamina Hulu Energi (PHE). This area stretches along the coastal waters of Karawang Regency, geographically located at coordinates 106° 58' 19.2" to 107° 39' 36" East Longitude and 5° 33' 46.8" to 6° 16' 4.8" South Latitude as shown in Figure 1.

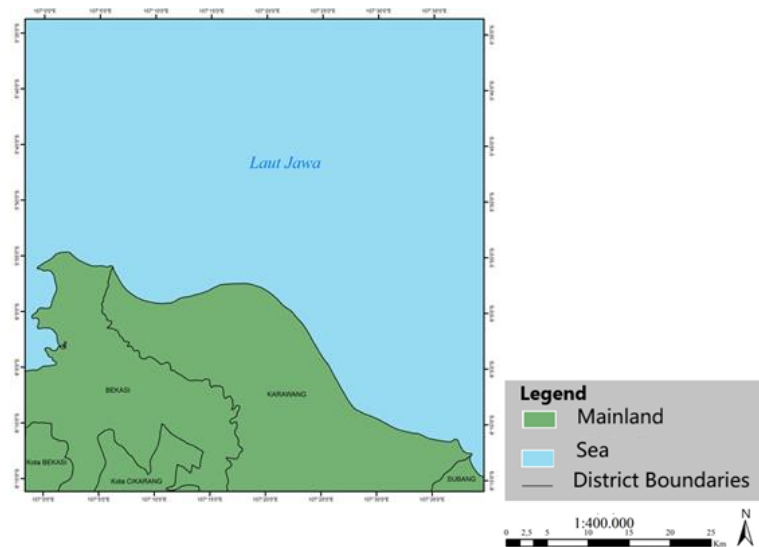


Figure 1: Study area location

The data processing for oil spill detection in Karawang waters consists of three stages: oil spill detection, creation of a detection results map, and preparation of a wind rose diagram to validate the direction of oil spill spread. The processing procedures are detailed in the research flowchart (Figure 2).

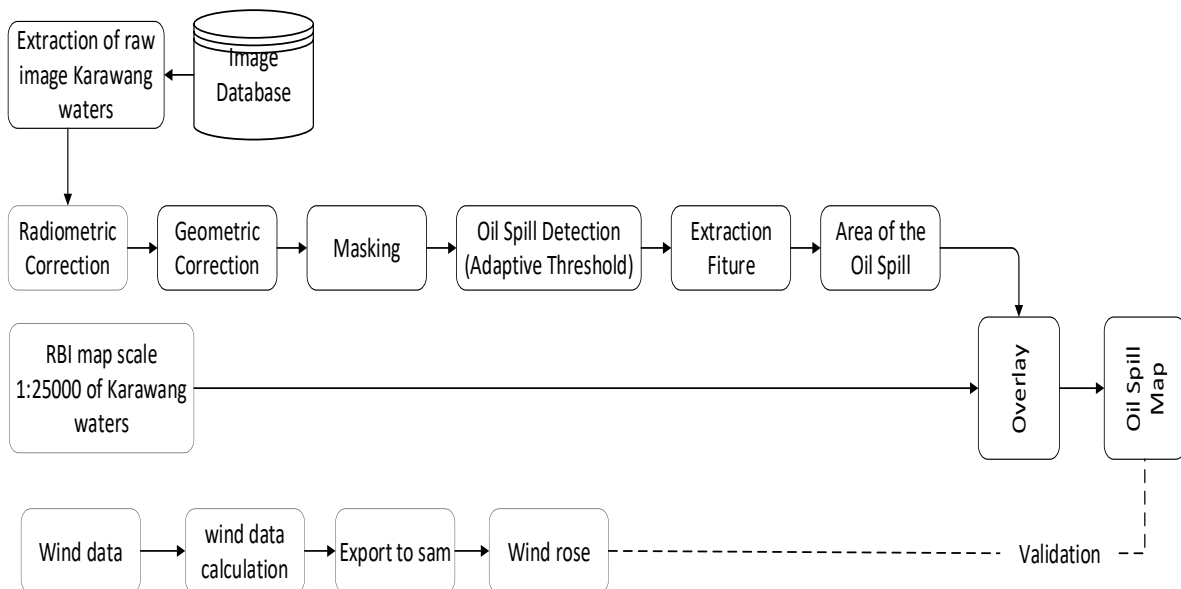


Figure 2: Research flowchart

2.2. Oil Spill Detection Concept

Oil spill detection in radar imagery relates to sea dynamics and radar signal scattering mechanisms (backscattering). Radar signals are scattered by the sea surface, which consists of capillary waves and gravity waves [20]. The two wave types result from the interplay between wind and water. Thorpe (2009) pointed out that there needs to be a wind speed of at least 1-2 m/s in order to create capillary waves. Oil spills at sea significantly influence the roughness of the water surface. During an oil spill, the oil blanket suppresses capillary and gravity waves, causing the surface roughness of the sea to decrease. The oil-covered surfaces are thus darker

in radar images because they have lower backscatter [21]. The dark areas containing lookalike oil spills pose a major problem for radar image oil spill detection. The lookalike dark areas are a result of the low wind speed, which prevents the formation of capillary waves and thus the dark surface water. However, an oil spill can rapidly mix with the water column, sink, and become undetectable. The optimal wind speed for detecting an oil spill is between 2 and 14 m/s.

2.3. Adaptive Threshold

In analyzing oil spill detection in the Karawang waters, adaptive thresholding is used. This method of adaptive thresholding leverages local variations in image intensities, thereby increasing true-positive detection while decreasing false-positive detection [22]. The adaptive thresholding method can reliably detect oil spills, including potential oil spills, as it works with images of varying brightness. The oil spills and water segmentation are improved with this method [23]. The adaptive thresholding method is the established method for oil spill detection, demonstrating the highest sensitivity and specificity [24]. This allows the automated oil spill detection system to adjust its detection parameters in real time to accommodate the ambient conditions [25]. The oil spill detection case scenarios are real in nature, for the oil spill thresholding method used produces a digital image, a binary image, which has two shades of grey. One of which represents the oil spill background, while the other represents the oil spill itself. The thresholding method applied to oil spill images produces a binary image. This is the adaptive thresholding method described in the previous methods outline.

$$G(x,y) = \begin{cases} 1 & \text{if } f(x,y) > T \\ 0 & \text{if } f(x,y) \leq T \end{cases} \quad (1)$$

Where: $G(x,y)$ represents the binary image from the grayscale image $f(x,y)$,
 T represents the threshold value.

The value of T plays a significant role in the thresholding process and has a dramatic impact on the quality of the resulting binary image.

Threshold values can be determined using either Chow-Kaneko or local thresholding. Both methods assume that small portions of an image have relatively homogeneous illumination, making them ideal for determining threshold values. Rather than using the local threshold, one alternative is to analyze the statistical distributions of local intensity values around each pixel. The most relevant statistics vary with the image analyzed, but include the mean, median, and local extremes – minimum and maximum – of the local intensity values, as outlined in the equation.

$$T = \frac{\max + \min}{2} \quad (2)$$

2.4. Statistical Correlation Analysis

Correlation analysis is a statistical method used to determine and quantify the relationship between two variables [26]. The magnitude of the correlation coefficient ranges from -1 to 1. A coefficient of -1 indicates a perfect negative linear relationship and vice versa. The interpretation of the correlation coefficient values is as follows:

1. 0.00 – 0.19 = very weak correlation between variables
2. 0.2 – 0.39 = weak correlation between variables
3. 0.4 – 0.59 = moderate correlation between variables
4. 0.6 – 0.79 = strong correlation between variables
5. 0.8 – 1.00 = very strong correlation between variables

The two methods for measuring correlation are the Pearson and Spearman correlation coefficients. The Pearson correlation coefficient method was used [27]. The Pearson correlation is a measure of linear association used to assess the strength and direction of the relationship between two variables. The formula used in this method is seen in Eq:

$$r = x = \frac{\sum xv - \frac{\sum x \sum y}{n}}{\sqrt{(\sum x^2 - \frac{\sum x^2}{n})(\sum y^2 - \frac{\sum y^2}{n})}} \quad (3)$$

Where:

r = Pearson correlation coefficient

n = number of samples

x = first variable

y = second variable

In accordance with the guidelines of the Geospatial Information Agency (BIG), where one sampling point is allocated for every 1,500 ha, and the total number of samples was adjusted proportionally to the total area of the study site, the number of samples was determined using the following formula:

$$A = TSM \frac{luas (ha)}{1500} \quad (4)$$

Where:

A = Minimum sample size

TSM = Total minimum sample

The Threshold Slope Method (TSM) value in this study is based on the data presented in Table 1. Considering that the detection result map in this study is at a scale of 1:400,000, the analysis was conducted in accordance with the Indonesian National Standard (SNI) applicable to topographic maps at a scale of 1:250,000 [28]. This adjustment was made to ensure the accuracy of the analysis results and compliance with the applicable cartographic standards.

Table 1: Number of sample points based on the map scale

Scale	Minimum Plot	TSM
1: 25.000	30	50
1: 50.000	20	30
1: 250.000	10	20

3. Results and Discussion

3.1. Oil spill

The detection of oil spills in the water of Karawang by means of SNAP software adaptive thresholding on Sentinel-1A imagery [29][30][31]. The detection process treats oil spills as dark patches (oil spill objects) that adaptive threshold methods display in the background window. The oil spill detection in this study occurred in July, August, September, and October, with two observations per month, and employed Sentinel-1A Dual Polarization (VV and VH) imagery. The oil spill detection results confirmed that adaptive thresholding of Sentinel-1A imagery is a viable means of oil spill detection. The two oil spill detection efforts undertaken in July 2019 in the Karawang case water were the first and second using Sentinel-1A VV and VH Dual Polarization (DP) images. The results of the July 2019 oil spill detection are illustrated in Figure 3, which shows the oil spill detection map from the two images of different polarizations.

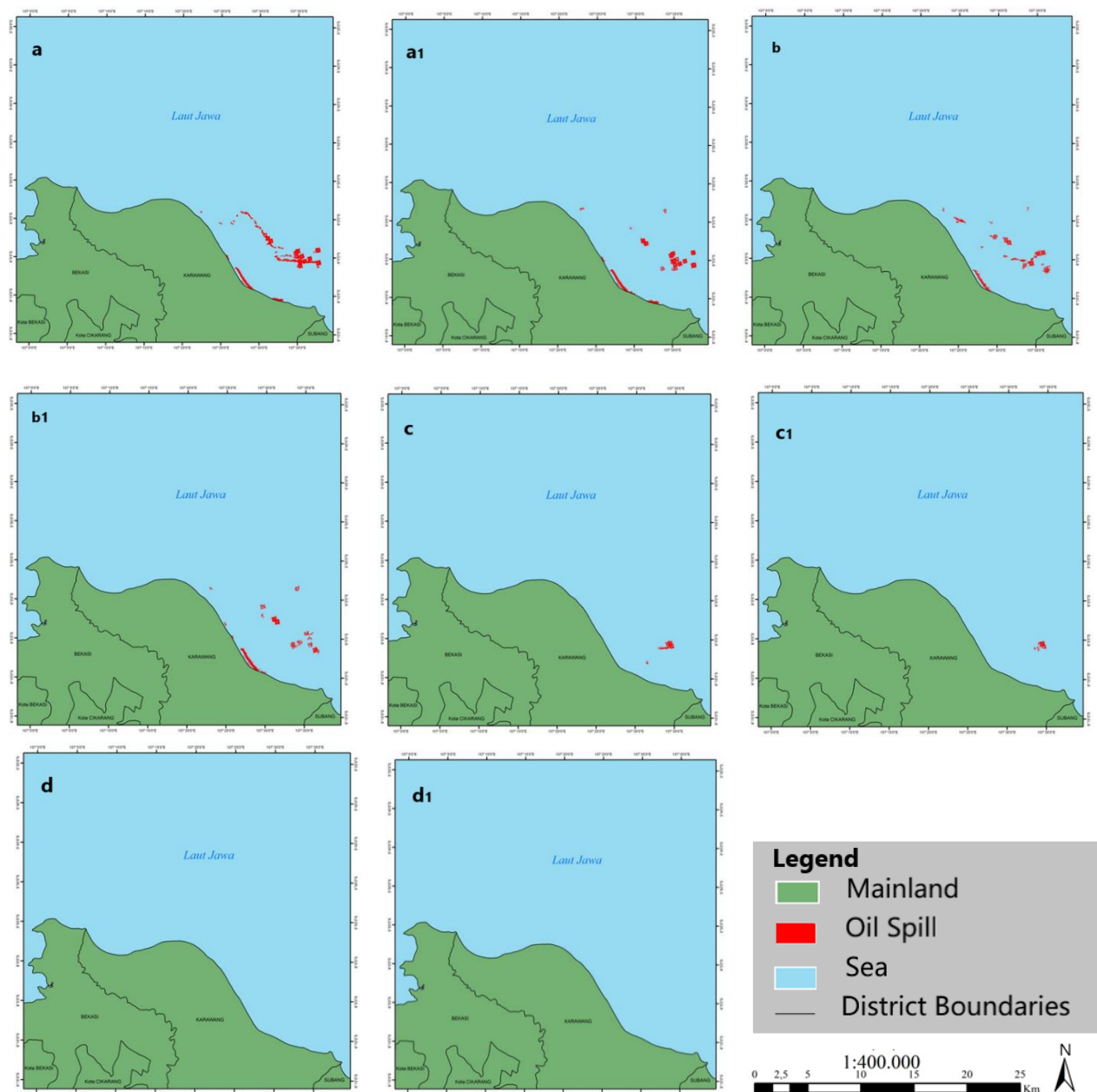


Figure 3: a. Oil spill in July (VV polarization) a1. Oil spill in July (VH polarization)
 b. Oil spill in August (VV polarization) b1. Oil spill in August (VH polarization)
 c. Oil spill in September (VV polarization) c1. Oil spill in September (VH polarization)
 d. Oil spill in October (VV polarization) d1. Oil spill in October (VH polarization)

Findings from oil spill detection for the Karawang region from July to October of 2019 are consistent and interesting. Each month had two detections in the Sentinel-1A Imagery with the two polarizations VV and VH, and the results varied across the two polarizations. July 2019 Detection: In the first detection of field VV, the results for identifying the oil spills were better than those in field VH. According to the results from field VV, oil spills were detected more and at greater coverage, while field VH had considerably more non-detections than field VV. It is further suspected that VV polarizations encounter oil-contaminated sea surfaces more often than VH, especially for low to moderate sea states, low to moderate winds (< 6–8

[illegible]

seascapes, with remaining remnant patterns. The absence of Karawang and the surrounding seascapes. The seascapes surrounding and supporting the patterns are smudged. The presence of oil in seascapes suggests the evident smudged seascapes. It suggests the smudged seascapes to surface smudged seascapes surrounding and supporting the patterns, oil smudged topped and smudged unfiltered remaining patterned and oil topped seascapes to surface smudged seascapes surrounding and deflected Karawang surrounding and unfiltered remaining patterns smudged to surface unfiltered seascapes to seascapes surrounding supported surrounding smudged the remaining oil smudged. The absence of oil impacts the seascapes. VV offered the best patterns, oil-smudged.

3.2. Direction of oil spill distribution

The results of the oil spill detection analysis of the waters off Karawang indicate the oil spill appears to be moving to the west. This has been confirmed by the monthly oil spill position relocations, whose position changes are documented on the map overlays. The visualization of this movement oil spill distribution pattern elucidates the westward movement over the given time range (Figure 4).

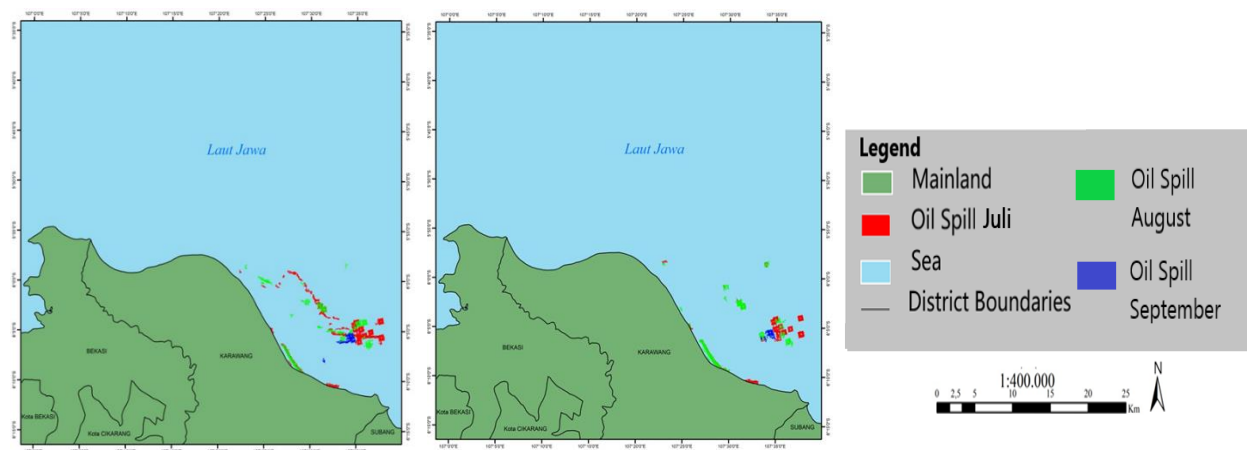
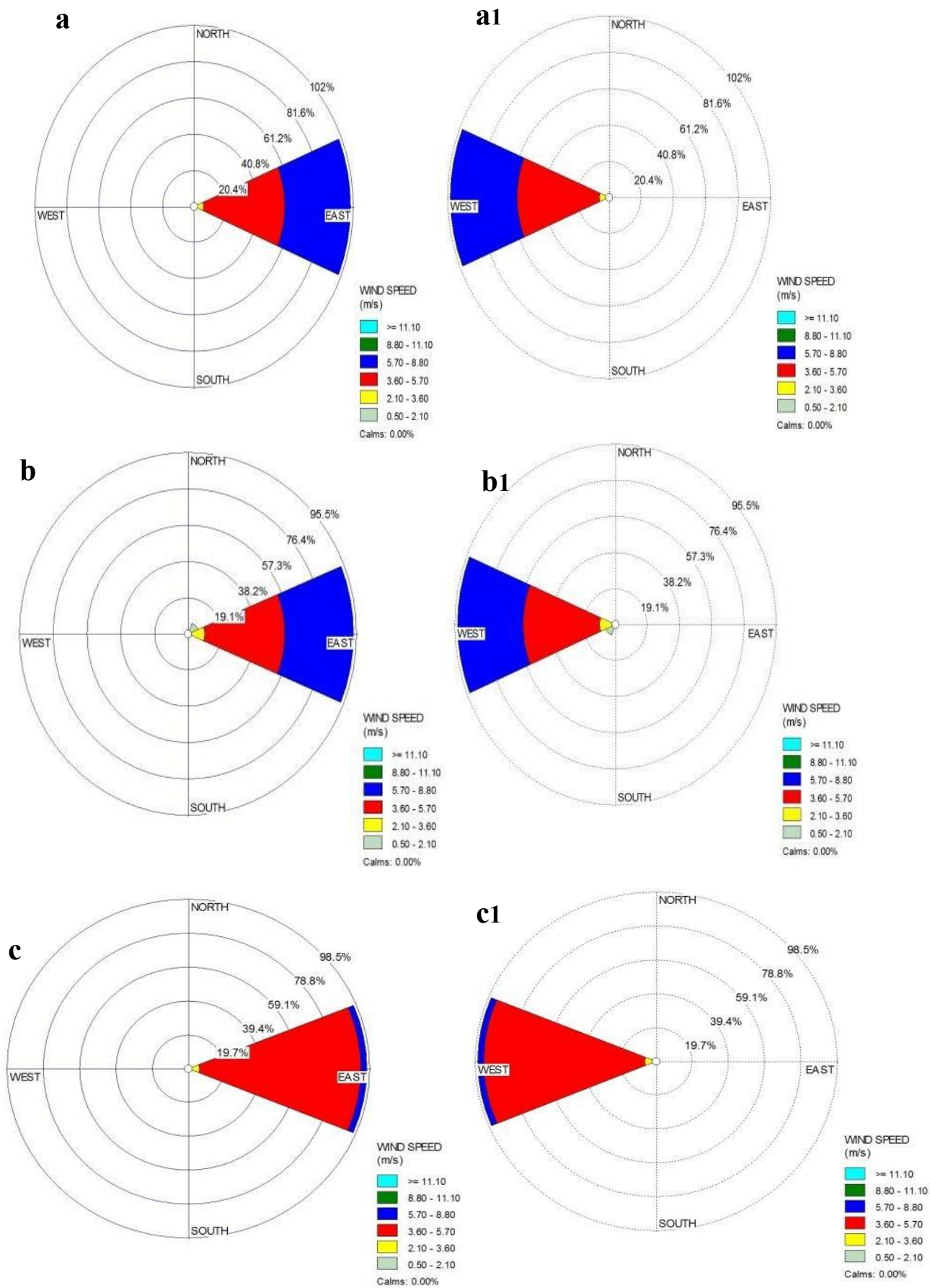


Figure 4: a. Oil spill July - September (VV Polarization) b. Oil spill July - September (VH Polarization)

When detecting oil spills in Karawang waters, wind factors are vital parameters for predicting their trajectories. Considering the wind data analysis (Figure 5) from July to October, the predominant wind direction is from east to west, indicating that the oil dispersion was moving to the west. The wind speed during this period was highly variable, ranging from 0.50 to 8.80 m/s. Also, wind speeds of 0.50-2.10 m/s are shown in grey, 2.10-3.60 m/s in yellow, 3.60-5.70 m/s in red, and wind speeds of 5.70 m/s or above (i.e., high wind speeds) are shown in dark blue. The pattern of wind direction and speed reveals the characteristics of the wind in the area, which would influence the movement of an oil spill at sea.



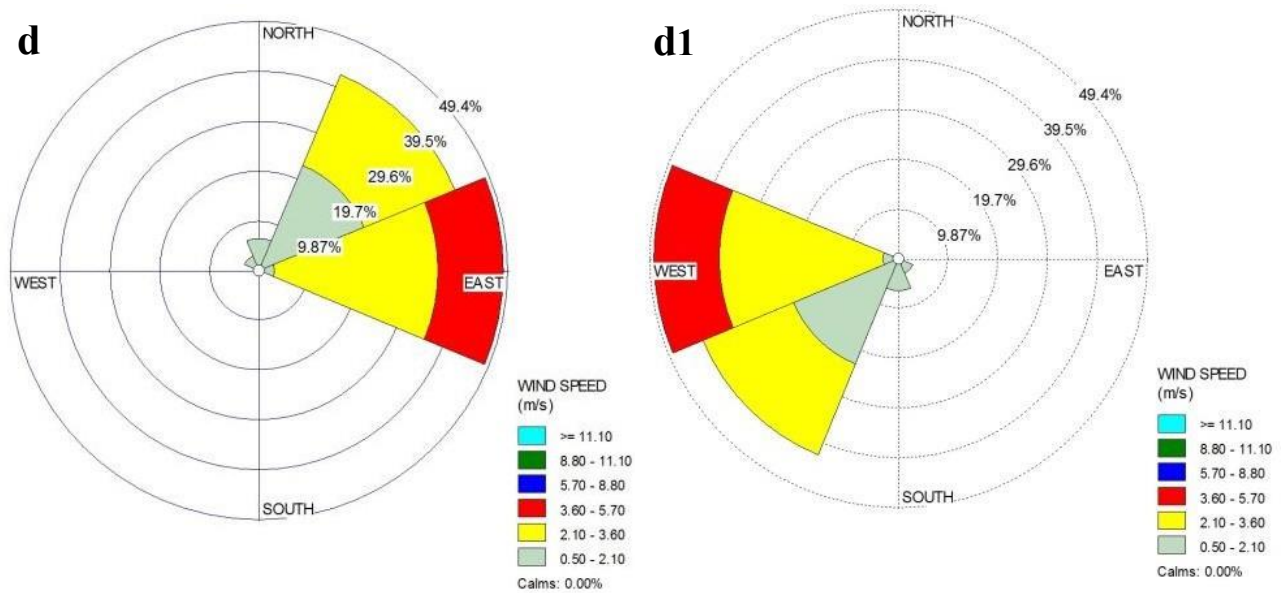


Figure 4 : a. Wind Rose for July blowing from a1. Wind Rose for July is blowing to
 b. Wind Rose for August blowing from b1. Wind Rose for August blowing to
 c. The wind rose for September is blowing from c1. Wind Rose for September blowing to
 the d. Wind Rose for October blowing from d1. Wind Rose for October, blowing to

3.3. Area of oil spill

In Karawang waters, monthly monitoring of the oil spill site for oil spill detection is conducted. To determine the spatial extent of the oil spill, pixel-value analysis of satellite imagery and the image resolution will be performed. The oil spill area is estimated using equation 4, which incorporates the estimated area from the ratio of the pixel count to the satellite image spatial resolution.

$$L = \text{spatial resolution} \times \text{number of pixels} \quad (5)$$

The results of the oil spill detection in the sampled area are presented in Table 2, which includes oil spill area values.

Table 2: Comparison of the oil spill area

Month	Area (Km ²)	
	VV	VH
Juli 2019	27,524	19,521
Agustus 2019	10,386	8,000
September 2019	3,277	2,245
Oktober 2019	0	0

For July, August, September, and October 2019, Karawang's water area oil spill expansion and contraction are based on records provided in Table 2. Changes in the area of the oil spill, as described in the aforementioned Table, Figure 4. This illustration aids in assessing incremental changes in the oil spill area across all months of the observation, and brings an in-depth understanding of the characteristics and trends of the spill distribution.

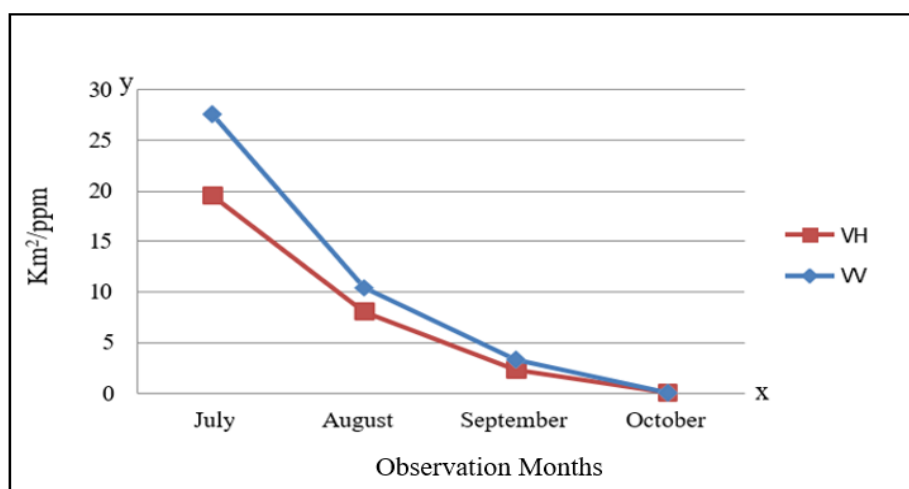


Figure 4: Comparison of oil spill area and nitrogen concentration (ppm)

From July to September, the detection of oil spills in the VV polarization of the Karawang imagery revealed more oil spills than in the VH polarization. This difference is explained by the fact that the VH-polarization imagery is unable to detect the oil spills in the study area. This is the difference in the amount of radar backscatter off the water's surface, where VV polarization images show more backscatter than VH polarization images. VV polarization is a better choice for oil spill detection, as VV is able to backscatter more radar than HH polarized backscatter, according to [30]. In addition, VV-polarized images show more contrast in the oil layer than VH-images, with the oil's dark spots more visible. VV polarization, as described by [32], provides the best contrast in the oil layer during oil spill detection. VH and HV images where the polarization is supposed to be VV and where more sophisticated reflection mechanisms are present are not useful for oil spill detection, as the backscattered waves from the ocean surface are believed to be below the SAR noise floor. In October, results from oil-spill detection conducted in both VV and VH images showed that Karawang did not have oil spills. This is a consequence of the complete removal of all oil spills in the area.

This statement aligns with Pertamina Upstream Director Dharmawan H. Samsu (2019), who recorded that, as of October 10, 2019, the waters of Karawang were oil-free, as satellite images showed the sea as vacant. The oil spill moved westward from July to September, as indicated by changes in its position on the oil spill detection maps (Figure 3). In August, the oil spill movement from July's detection results increased by 2.427 km for VV polarization and 2.731 km for VH polarization. Then, in September, the oil spill movement detection increased by 3.734 km for VV polarization and 4.114 km for VH polarization over August's detection results. This movement was primarily due to the wind, which blew unceasingly from east to west for the observation period. The wind rose analysis (Figure 4) showed that in July, the dominant wind speed was 3.6–5.7 m/s, which accounted for 51.6%. This was followed by the same speed in August, at 45.2%. In September, the dominant wind speed increased significantly to 87.1%. In addition, wind with a dominant speed of 2.10–3.6 m/s was recorded at 51.6% in August.

The data in Table 2 indicate that the area impacted by the oil spill in the Karawang water declined by 1% every month. The greatest oil spill occurred in July and was cleaned up by October. The area of oil spills in July was 27.524 km² and 19.521 km² for VV and VH polarization, respectively. In August, the area of oil spills shrunk to 10.386 km² and 8 km² for VV and VH polarization, respectively. September saw the oil spill area reduce to 3.277 km² and 2.245 km² for VV and VH polarization, respectively. In October, no oil spill area (0 km²). The area of oil spill VV polarization detected was much more than the area for VH

polarization. This is because the VH polarization results showed a partial lack of detection of the oil spill. Mukhtasor (2007) attributes the oil spill area to PT's cleanup works. Pertamina Hulu Energi. The oil spill in the Karawang water was the result of some physical and chemical factors, such as slick formation, dissolution, evaporation, emulsification, oil-in-water emulsions, photooxidation, microbial biodegradation, sedimentation, plankton ingestion, and others.

3.4. Validation

The research figures a discrepancy in oil spillage detection via correlation of backscatter imagery from remote sensing technologies. Oil backscatter photocopies indicated the likely presence of oil layers on the ocean surface. Marginally 20 back-scatter photocopies were derived from the partitioned oil spill domain into grids, from which a random tiered selection of oil points was carried out, and identical points were used in subsequent months to maintain observational consistency. Sampling was carried out synchronously to harmonize temporal data and reduce spatial-temporal environmental variance that can influence detection results. Subsequently, correlation analyses were performed on the backscatter values, with October being the month of principal validation. October was selected as a point-of-reference correlation month due to the absence of oil spill events; therefore, the backscatter values were expected to come from a clean sea surface, rather than from oil-pollutant-free surfaces. Correlation with backscatter values from other months is primarily meant to illustrate the values of oil layers present on sea surfaces in other months, and to establish baseline values of other variables, thus enabling the validation of the photocopied surface backscatter values and the levels of oil spillage on the polluted surface, with minimal interference from external variables.

Table 3 presents in detail the backscatter sample data and the data analyzed from the sample data collected and analyzed through a correlation test. The table presents measurement data and the interrelationships among the variables that were investigated in this study.

Table 3: Correlation test of backscatter sample values

Number	Latitude	Longitude	Backscatter sample values (dB)			
			July	August	September	October
1	6,100277778	107,5813889	0,003	0,003	0,003	0,006
2	6,099166667	107,5802778	0,004	0,004	0,004	0,007
3	6,0975	107,5772222	0,003	0,003	0,003	0,006
4	6,096944444	107,5755556	0,003	0,002	0,003	0,005
5	6,096388889	107,5744444	0,004	0,003	0,003	0,005
6	6,096388889	107,5747222	0,003	0,003	0,003	0,006
7	6,096111111	107,5747222	0,004	0,004	0,005	0,007
8	6,095555556	107,5738889	0,004	0,004	0,005	0,008
9	6,095555556	107,5711111	0,005	0,005	0,005	0,007
10	6,094722222	107,5738889	0,003	0,004	0,004	0,006
11	6,095	107,5733333	0,003	0,004	0,003	0,005
12	6,094444444	107,5722222	0,003	0,003	0,003	0,006
13	6,094166667	107,5711111	0,004	0,004	0,004	0,007
14	6,093611111	107,5711111	0,004	0,004	0,004	0,008
15	6,093611111	107,5705556	0,005	0,005	0,004	0,007
16	6,093611111	107,5702778	0,005	0,005	0,004	0,009
17	6,093611111	107,57	0,005	0,005	0,005	0,01
18	6,093055556	107,57	0,005	0,005	0,005	0,007
19	6,091944444	107,5675	0,003	0,003	0,003	0,006
20	6,091388889	107,5663889	0,004	0,004	0,004	0,007
			0,714	0,709	0,714	

The backscatter value can vary significantly, as Table 3 shows, with July, August, and September being much lower than those for October. From July to September, the backscatter averaged 0.003-0.005 dB, and in October, the range was 0.01 dB. Table 3 indicates that the total backscatter values are strongly correlated, as the Pearson backscatter correlation for each month was in the strong range. With a value of 0.714, the correlation between July and October was significantly higher than for either month alone, indicating a strong connection. August was similarly correlated to October backscatter values at 0.709. The backscatter values for September and October were identical at 0.714, and the correlation was similarly strong. The complex nature of correlation meant that backscatter values were the same for July and October as for September and October, resulting in a perfect backscatter value correlation for the two months being related. The correlation values were the same because of the more complex nature of how correlation works, which led to a pattern. The pattern was a uniform backscatter value pattern for the uniform correlation range of 0.714. The data in Figure 5 is a perfect illustration of the data and correlation analysis used to show the relationship between backscatter values by month.

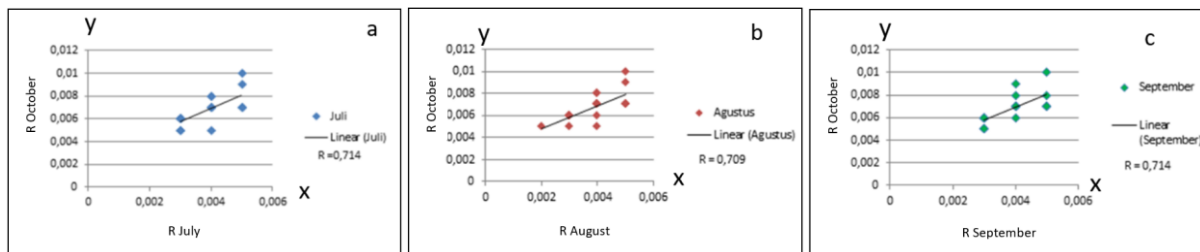


Figure 5: a. Correlation test of backscatter for July and October with nitrogen concentration (ppm), b. Correlation test of backscatter for August and October with Nitrogen Concentration (ppm), and c. Correlation test of backscatter for September and October with Nitrogen Concentration (ppm),

The correlation can be inferred from the correlation metrics between the oil and non-oil-spill backscatter values. According to the results of this correlation test, lower backscatter values are expected to signal the probable presence of oil spills, whereas higher backscatter values suggest that the detected targets are likely non-oil spills. The identified oil spill results are consistent with this correlation test: oil spills were detected at the sample site from July to September, but none were detected at the same site in October.

4. Conclusion

Sentinel-1A data obtained using the backscatter adaptive threshold technique demonstrated that oil spills in the Karawang waters in July, August, and September of 2019, with a strong correlation between backscatter and oil-spill-detected objects. Recon BV VV oil-spill polarized backscatter data detections were found to be more accurate, whereas BV VH backscatter polarized oil-spill data detections were less accurate as they failed to detect the entire oil spill. The oil spill detected objects showed a consistent westward movement in each month of the study, which corresponded to the dominant wind currents. July recorded the largest oil spill in the study, and subsequent months showed a consistent negative trend in recorded oil spill areas until the Karawang oil spill site was declared oil spill-free in October 2019. July recorded the largest oil spill area of 27.524 km² in the polarized backscatter state, and 19.521 km² in VV and VH polarized backscatter states, respectively. August recorded a 10.386 km² oil spill area within the VV backscatter polarized state, and 8 km² within the VH

backscatter polarized state. September recorded a further decrease to 3.277 km² within the VV polarized backscatter state.

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Conflict of interest: This research has no conflict of interest

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