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Oil Spill Detection using Sentinel-1 Multitemporal Data in Offshore Karawang

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ABSTRACT - Oil spill is a serious problem that could lead to economic and ecological losses, both in the short and long term. On July 12, 2019, there occurred an oil leakage around YYA-1 oil platform of Pertamina Hulu Energi Offshore North West Java (PHE ONWJ), located off the northern coast of Karawang, Java Sea. This incident has caused the death of fishes and marine animals, damage to coral reefs, mangroves, and seagrass beds, and several health problems of coastal communities. Therefore, it is necessary to map and monitor oil spills, so that actions can be taken to prevent the spread of oil spills. This study aims to map the distribution of oil spills in Karawang sea using multitemporal Sentinel-1 data from July to September 2019. The detection is carried out using the adaptive thresholding algorithm combined with manual interpretation. The result shows that the oil spills spread around Karawang sea from YYA-1 platform to Sedari Village and there are oil spills spreading from the Central Plant F/S platform. The oil spills tend to shift westward from July to September 2019. This shifting is supposed to be influenced by current and wave factors that were dominant moving westward at that time. Based on data processing, it was found that the oil spill area from July to September was respectively 24.79 km^2, 20.05 km2, and 27.12 km^2.

Keywords: oil spill, Sentinel-1, adaptive thresholding.

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INTRODUCTION

Indonesia has abundant marine resources including oil and natural gas, so that many exploration activities are carried out in the marine area. These conditions are more intensive with the focus shifting of upstream oil and gas activities from onshore fields to offshore and deep-sea areas (Azizi, 2018). This activity poses risks to the marine environment, including oil spill due to the damage of the oil platform.

Oil spill in the sea is a serious problem that has occurred in several countries, which caused by oil and gas exploration activities. These incidents can cause economic and ecological losses, both in the short and long term. If not addressed immediately, the oil spill may spread and cause greater negative impact on the surrounding area and this spread are affected by wind and current factors (Marsya, *et al.*, 2012).

The losses arising from several cases of oil spills due to oil and gas exploration activities are very large. One of the biggest cases of an oil spill ever was the Deepwater Horizon incident in the Gulf of Mexico in 2010 (Adams, 2015). According to Lee, *et al.* (2018), this incident caused a loss of up to 144.89 billion US dollars. The ecological impacts of this incident include the deaths of approximately 5,000 marine mammals, 1,000 turtles, nearly one million seabirds, a reduction of more than 85 percent of seaweed diversity, and damage to deep-sea coral reef communities (Adams, 2015). A study projects the economic impact of this incident in the form of a commercial, recreational, and marine aquaculture loss was 8.7 billion US Dollars with more than 22,000 jobs projected to be lost (Sumaila, *et al.*, 2012). Meanwhile, one of the cases of oil spills in Indonesia, namely the oil spill in Balikpapan, was estimated to have caused losses of up to 8.27 billion US Dollars (Greenomics, 2018). Another case, namely the oil spill in Montara, East Nusa Tenggara, caused significant losses as well. According to Alfa (2013), the total losses in 2012 caused by the oil spill in Montara were estimated at IDR1.7 trillion for seaweed f armers, IDR168 billion for fishermen, and IDR165 billion for the tourism sector.

On July 2019, the oil and gas leakage occured around the YYA-1 offshore platform of Pertamina Hulu Energi Offshore North West Java (PHE ONWJ), a few kilometers north of Karawang coast, Java Sea (Pertamina, 2019). According to Ministry of Energy and Mineral Resources on Kumparan.com (2020), the oil spill allegedly caused by the premature explosion that damages the drill pipe and subsoil. This incident has caused the death of fish and other marine animals, damage to coral reefs, mangroves, and seagrass beds, as well as several health problems of coastal communities. As a result of this incident, a total of 18,772 fishermen lost their sources of income. In August 2019, fishermen asked Pertamina to pay compensation of IDR168.948 billion equivalent to the daily losses suffered by fishermen for 60 days starting from the oil spill incident (Manalu & Issetiabudi, 2019).

Considering the number of losses incurred by oil spills, information related to the distribution of oil spills spatially and temporally is crucial to help authorities control the widespread of oil spills and reduce the losses. Satellite-based remote sensing is an alternative that can be used in mapping oil spill effectively with wide coverage. The information obtained from mapping using satellite-based remote sensing can be used as a basis for preventing the spread of oil spill, designing mitigation strategies, and calculating compensation.

Oil spill detection and mapping using satellite-based remote sensing technology have been used in response to oil spill incidents in the Gulf of Mexico (Friedman, *et al.*, 2002), South Caspian Sea (Ivanov, *et al.*, 2013), the coast of Mumbai, India (Misra & Balaji, 2017), and Balikpapan Bay (Prastyani & Basith, 2019; Sulma, *et al.*, 2019). Satellite-based imageries, either with active sensors, passive sensors, or a combination of the two, are often used in mapping and monitoring oil spill (Solberg, *et al.*, 2007; Bayramov, *et al.*, 2018; Brekke & Solberg, 2005). Various remote sensing technologies and methods can be used for oil spill mapping. One of them is Synthetic Aperture Radar (SAR) which can be relied on as an easy and economical means because it has the ability to record data in various weather conditions, the ability to penetrate clouds, can be used both day and night, and has a wide synoptic coverage. This is in line with Ivanov, *et al.* (2002) research which states that oil spill detection requires a solution with a system that provides observation on various weathers, free from all irradiation conditions and cloud cover, able to define the position, type, and volume of oil spill in real-time.

Researches related to the detection of oil spill in the sea using SAR with various methods have been carried out. In general, the methods used are manual, automated, and semiautomatic methods. Manual methods spend more time because dark spot need to be analyzed one by one by trained operators. Automated methods are more efficient, time-saving, and reliable in oil spill detection (Solberg, *et al.*, 1999; Marghany, 2001; Nirchio, *et al.*, 2005; Brekke & Solberg, 2005; Marghany, 2001). Semiautomatic methods are usually based on supervised classification, so it takes time to prepare the training area and is sufficiently dependent on the operator. However, the result of semiautomatic methods are slightly better than automated methods (Osmanoglu, *et al.*, 2013).

Misra & Balaji (2017) conducted a study of oil spill detection using texture analysis approaches and adaptive threshold algorithms on SNAP oil spill detection tool with SAR data that showed good and effective result in terms of time and cost. Prastyani & Basith (2018) in their research used Sentinel-1 SAR imagery for oil spill mapping in Balikpapan. The result shows that semiautomatic methods using differencing and automated methods using SNAP oil spill detection tool produce good oil spill map in a short time, so that they are cost and time effective. Another technique commonly used, namely visual interpretation techniques using active sensor data from Sentinel-1 satellite imagery and supporting data from Modis Aqua sensors has also been proven to be able to detect oil spill (Prastyani & Basith, 2019). Putranto, *et al.* (2016) utilize Sentinel-1 data using dark spot detection with adaptive threshold algorithm to analyze oil spill in a multitemporal manner.

In this study, SAR imagery is used since it has the capability to operate in all weather conditions, can penetrate clouds, and is free from sun glitter compared to optical imageries. Sentinel-1, which is a SAR-based imagery, is used in this study primarily because it is free of charge and effective for mapping oil spills in multitemporal cases (Prastyani & Basith, 2019; Misra & Balaji, 2017; Putranto, *et al.*, 2016). Sentinel-1 imagery is expected to map oil spills accurately in a short time, so that it helps related parties to develop better strategies for preventing the spread of oil spills. Hence, this study was conducted to map the oil spill in a multitemporal manner by utilizing Sentinel-1 data in offshore Karawang, Java Sea.

METHODOLOGY

Research object is in Karawang, Java Sea offshore. Geographically, this area is located on 5° 83' 11.712" S to 6° 11' 13.56" S and 106° 53' 13.992" E to 107° 35' 25.26" E (Figure 1). The coastline length of Karawang is 57 km and is dominated by clayey soil that has small particle size that could easily be carried by the sea current, resulting in its proneness to abrasion. The coastline and sea of Karawang Regency is abundant in natural resource, such as mangrove, coral reefs, sea biological resources, as well as brackish water dikes.

The main data used in this study is remote sensing data of Sentinel-1A. Since this study is a multitemporal study, three imageries on July 18, 2019, August 23, 2019, and September 4, 2019 are used. Both of those imageries are GRD type product and acquired in Interferometric Wide- swath (IW) mode. Another supporting data also used in this study to assist the analysis of oil spill movement and spread, such as wind and current direction data. Those supporting data come from literature studies.

This study of oil spill mapping is carried out using adaptive thresholding algorithm (Solberg, *et al.*, 2004) of the SNAP oil detection tool combined with manual advanced interpretation. This combination is efficient, time-saving, and able to reduce the noises, so it will be better than automated methods. The advanced interpretation performed by considering the shape of the oil spill, its proximity to the source of the spill, and wind speed. Wind speed, as the environmental factor that most influences oil spills detection using SAR, is carried out using using SNAP wind field estimation tool. The complete flowchart can be seen in Figure 2.

RESULTS AND DISCUSSION

Oil Spill Detection using SNAP Oil Spill Detection Tool

The result of oil spill detection using the SNAP oil spill detection tool for each imagery shows some dark spot clusters that are detected as oil spill but do not have a shape like oil spill. These clusters are marked with a yellow circle/ellipse as can be seen in Figure 3. According to Pavlakis (2001), oil spill is generally linear, straight, or angular in shape. Meanwhile, these clusters are random-shaped and irregular, so it is assumed that they are not oil spill. References corroborate this interpretation, so that these clusters are removed from the detected oil spill feature.

The oil spill clusters were also found in the north of the leakage location, the YYA-1 PHE ONWJ oil platform, which is marked in light blue in Figure 3. These clusters are suspected to be oil spill due to their linear and regular shape. They also have spatial proximity with Central Plant F/S PHE ONWJ. These oil spill clusters are suspected to have been caused by the oil and gas exploration activities of the Central Plant F/S PHE ONWJ.

Based on visual observations of the July 18, 2019 imagery, there are parts of the imagery that are suspected to be oil spill but were not detected as oil spill based on SNAP oil spill detection tool. These sections are marked with a pink circle/ellipse in Figure 3. The interpretation is based on their tone that looks darker than the surroundings and forms a linear pattern with the cluster detected as oil spill. These sections are interpreted and digitized as part of the oil spill feature later.

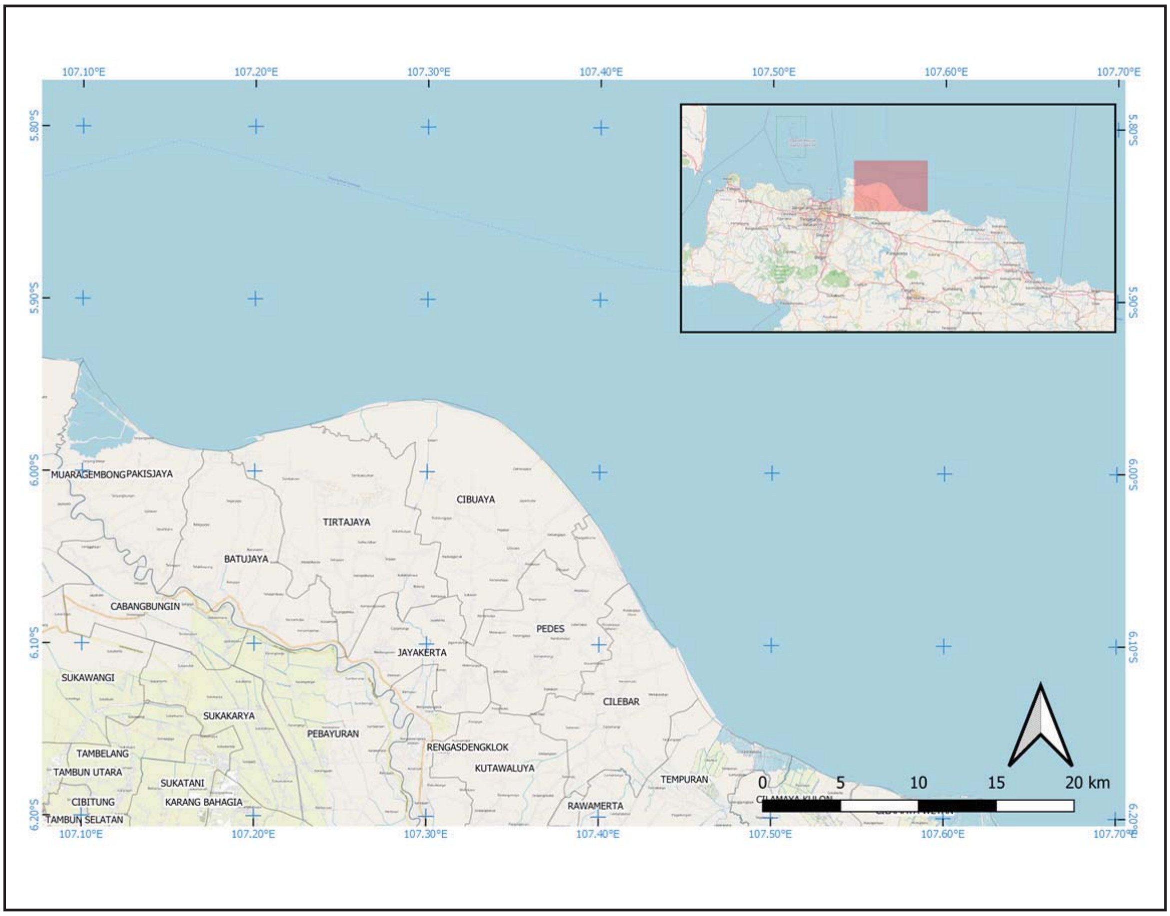

Figure 1
Area of research.

Oil Spill Analysis Based on Wind Speed

The wind speeds around the oil spill of July 18, 2019, August 23, 2019 and September 4, 2019 respectively have averaged values of 5.2 m/s, 7.7 m/s and 5.5 m/s. The map can be seen in Figure 4. All of these values fall into the 3 to 7-10 m/s range which, according to Brekke & Solberg (2005), only causes a slight misinterpretation of oil spill. However, the optimal wind speed for detecting oil spill of 5-6 m/s according to Jones (2001), only satisfied by wind estimation on July 18, 2019 and September 4, 2019.

According to Prastyani & Basith (2019), the accuracy of wind speed estimation result of the CMOD5 model has possible inaccuracies which can be caused by atmospheric dynamics. Although the wind speed estimation model produce the ideal wind speed for oil spill detection, it is important to do a visual shape analysis to reduce misdetection.

Backscatter Value of Oil Spill

The oil spill backscatter value observation result for each transect can be seen in Table 1. Based on the observations, it can be interpreted that in the same imagery, the dark spot which is an oil spill tends to have a lower backscatter value than the backscatter value of non-oil spill dark spot or undetected oil spill.

The observation from the three imageries shows that the August 23, 2019 imagery has the highest average backscatter value of the oil spill dark spot, namely, -21.43 to -19.85 when compared to the other two imageries. This is presumably caused by its wind speed (7.7 m/s) that is higher than the other two imageries (5.2 m/s and 5.5 m/s). The faster winds can generate currents and waves, making the sea surface appear rougher and as a result, the backscatter signal received by the SAR sensor is higher. Visually, it can be observed that the August 23, 2019 imagery also shows a clearer current direction than the other two imageries.

The Spread and the Result of Oil Spill After Advanced Interpretation

Based on the advanced interpretation, oil spill map is generated as presented on Figure 5. Based on the interpretation of shapes and patterns, there are several clusters detected by the SNAP oil spill detection tool which are suspected not to be oil spill, because they have a random and irregular shape. After being verified based on the reference shape, these clusters are suspected to be noise, so that they are removed from the oil spill feature class. Advanced interpretation also detects dark spots of the oil spill that is not detected as oil spill based on the SNAP oil spill detection tool. These dark spots then being digitized and clustered as part of the oil spill. The area of the oil spill after advanced interpretation on July 18, 2019, August 23, 2019 and September 4, 2019, are 24.79 km^2, 20.05 km^2 and 27.12 km^2, respectively. In general, the oil spill was divided into two parts, specifically the oil spill caused by the YYA-1 platform and the oil spill caused by the Central Plant F/S. The interpretation result of the July 18, 2019 Sentinel-1 imagery shows that the oil spill is spread around the northeast of Offshore Karawang mostly. At that time, the oil spill caused by the YYA-1 platform spread over ±32 km with a flocking pattern and slightly straight shape. Meanwhile, the oil spill caused by Central Plant F/S spread in a straight pattern like a track. The oil spill extends ±9 km and the furthest part is ±12 km from Central Plant F/S.

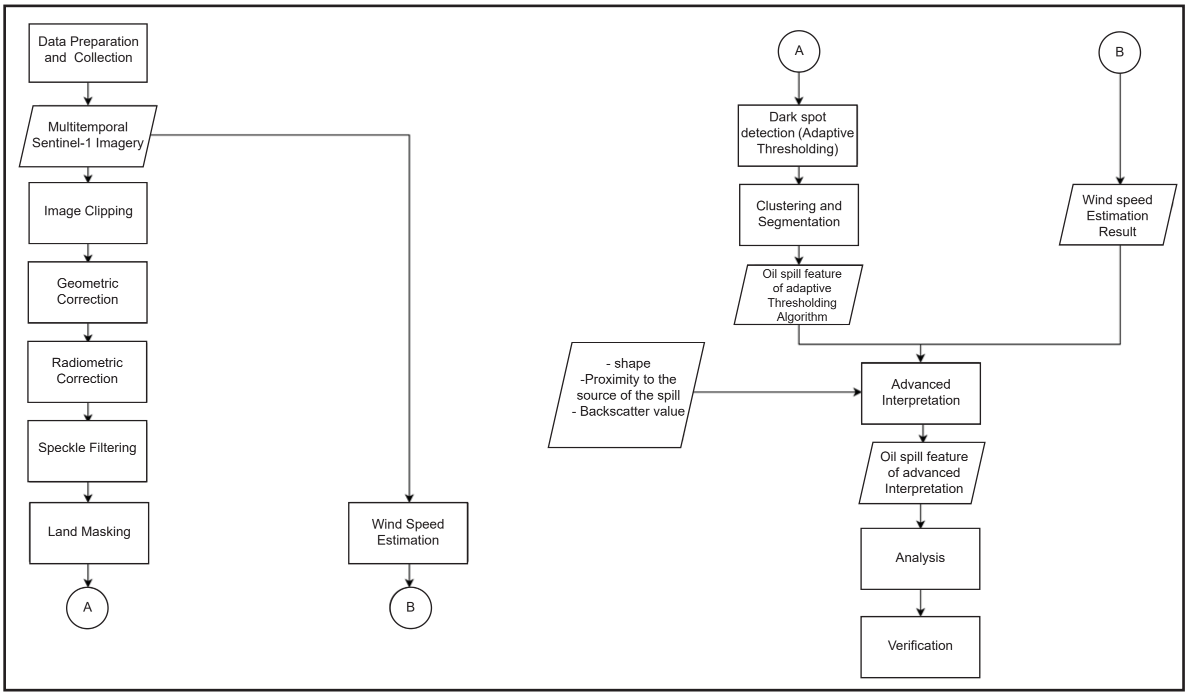

Figure 2
Flowchart of methodology.

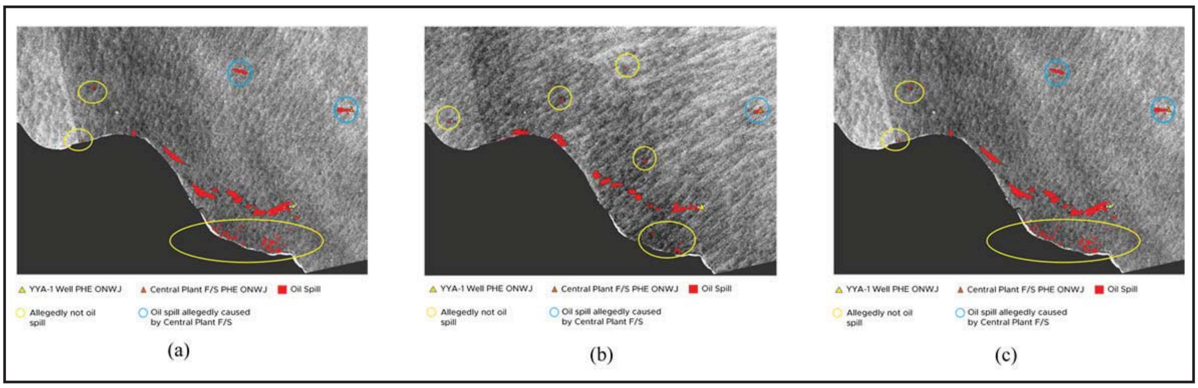

Figure 3
The result of oil spill detection in offshore Karawang using the SNAP oil spill detection tool on (a) July 18, 2019, (b) August 23, 2019, (c) September 4, 2019 Sentinel-1 imagery.

Table 1
Backscatter value of dark spots

Imageries Date	Transect	Mean of backscatter value	Explanation
18-Jul-19	1	-25,47	Oil spill
	2	-23,71	Oil spill
	3	-23,31	Oil spill
	4	-19,92	Undetected oil spill
	5	-21,05	Not oil spill
23-Aug-19	1	-19,85	Oil spill
	2	-21,43	Oil spill
	3	-19,90	Oil spill
	4	-18,81	Not oil spill
	5	-19,05	Not oil spill
4-Sep-19	1	-25,13	Oil spill
	2	-24,55	Oil spill
	3	-24,59	Oil spill
	4	-21,89	Not oil spill
	5	-20,13	Not oil spill

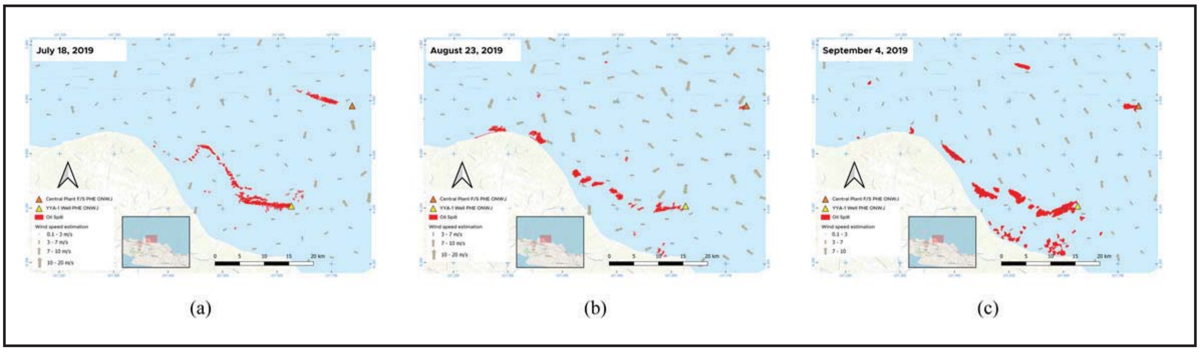

Figure 4
Oil spill map based on adaptive thresholding algorithm detection along with wind speed information on (a) July 18, 2019, (b) August 23, 2019, (c) September 4, 2019.

The interpretation result of the August 23, 2019 Sentinel-1 imagery shows that the oil spill was relatively closer to the coast than the July 18, 2019 oil spill. The oil spill caused by the YYA-1 platform spread up to ± 45 km and had reached the Karawang coastal area, precisely, Sedari Village and Cemarajaya Village. The oil spill distribution pattern tends to form separate groups with a slightly more rounded shape compared to the previous period. Meanwhile, the distribution of the oil spill caused by Central Plant F/S is limited to only around 2 km radius from Central Plant F/S.

The interpretation result of the September 4, 2019 Sentinel-1 imagery shows that the oil spill caused by the YYA-1 platform spread up to ±37 km and reached Karawang coastal area, precisely, Sedari Village. In general, the oil spill pattern tends to be in groups with a straighter shape. The oil spill caused by Central Plant F/S spread into two separate parts. They are the part that intersected exactly with the location of Central Plant F/S and the part which separated about 25 km to the west of Central Plant F/S. The separated oil spill is still believed to have originated from the F/S Central Plant since it is not further than the spread of the oil spill caused by the YYA-1 platform that reached ±32 to ±45 km in distance. Overlay map of the oil spill detection derived from three Sentinel-1 imageries can be seen in Figure 6.

Movement of Oil Spill and Verification

Based on the interpretation of Sentinel-1 imagery, the oil spill tends to move westward. The movement of the oil spill towards the west was caused by the direction of the wind and currents that tended to the west. This is in line with the wind direction model in Offshore Karawang which according to Agus, *et al.* (2020), heading west around September. Based on current direction, according to Wyrtki (1961), surface currents in the Java Sea tends to move westward around June-August and this condition is in line with the current model from Ningsih, *et al.* (2000). The current model by Agus, *et al.* (2020), also shows that the direction of the current

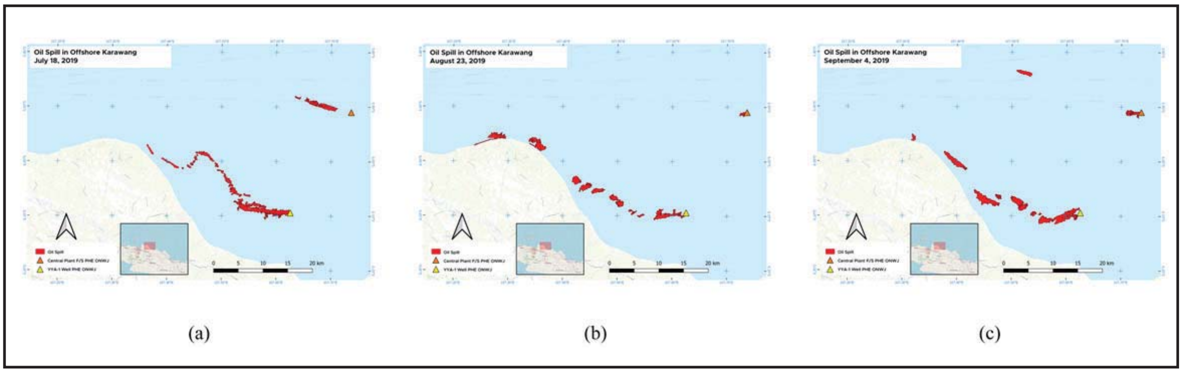

Figure 5
Oil spill detection results after advanced interpretation on
(a) July 18, 2019, (b) August 23, 2019, (c) September 4, 2019.

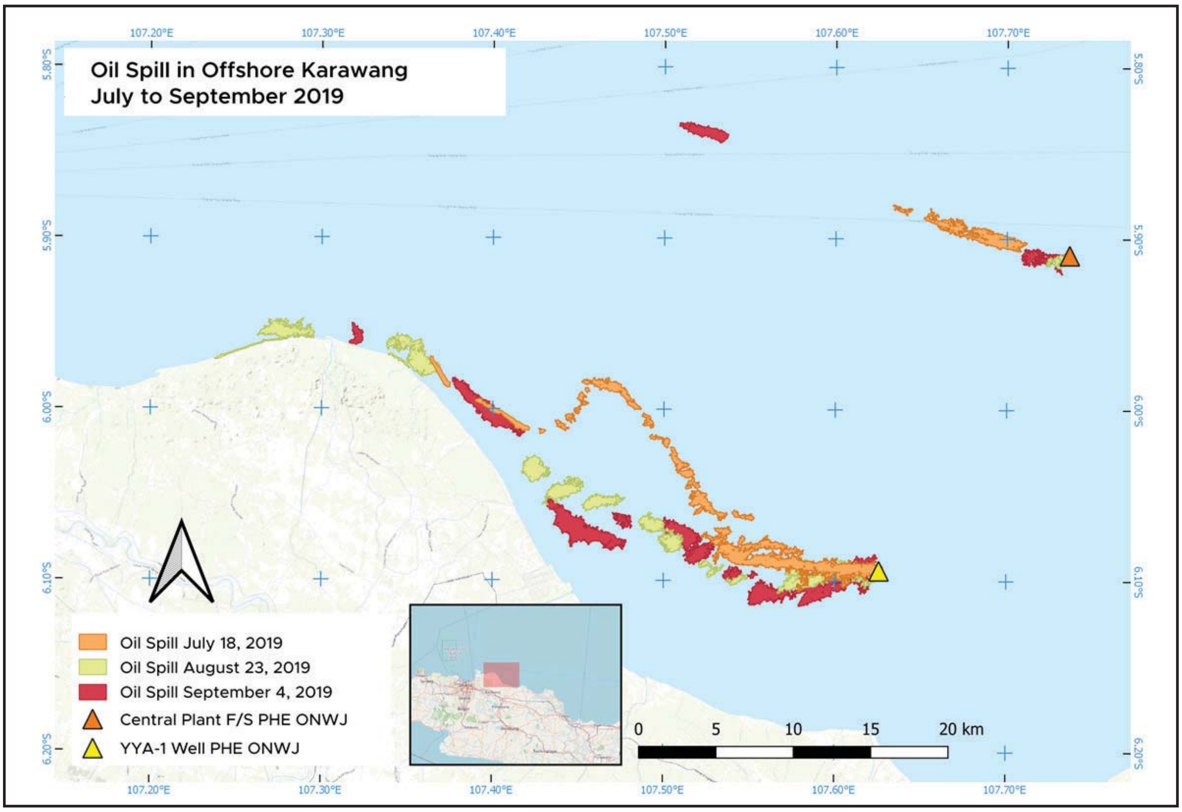

Figure 6
Overlay map of oil spill detection in offshore Karawang July to September 2019.

Table 2
Verification table of oil spill between this study and LAPAN data

Imagery Date	Oil spill area (km^2)		Confirmed oil spill area (km^2)	Percentage of oil spill area to the result of this study (%)	Percentage of oil spill area to the LAPAN data (%)
	This study	LAPAN data			
18-Jul-19	24,79	17,00	14,16	57,11	83,31
23-Aug-19	20,05	24,55	15,99	79,73	65,12
4-Sep-19	27,12	40,21	22,41	82,64	55,74

on the Karawang coast tends to move from east to west following the direction of the wind that blows according to the occurring season.

The area of oil spills from July to August tends to decrease. This was likely due to the cleaning efforts carried out by Pertamina by intensively removing the oil spill with fishermen's assistance as well as installing offshore oil booms and fishnet (Pertamina, 2019b; Pertamina, 2019c). Meanwhile, the area of the oil spill from August to September which tends to increase was allegedly caused by the unfinished process of relief well drilling. The intercept process where the relief well was successfully connected to the YYA -1 well, was just completed as of Saturday, September 21, 2019 at 10.30 (Pertamina, 2019d).

The results of this study need to be verified to measure how well they are. Verification is done by comparing the result of this research with the reference data released by National Aeronautics and Space Agency/LAPAN (LAPAN 2019) as well as with additional information such as news of several online media. A visual comparison between the two data can be seen on Figure 7.

Visually, the result of oil spill detection in this research has a similar shape to the oil spill data released by LAPAN, especially for oil spill close to the coast or the oil spill caused by oil and gas exploration activities on the YYA-1 platform. However, the part of the oil spill that is presumed to have been caused by the oil and gas exploration activities of the Central Plant F/S in this research is not mapped in the data released by LAPAN. In fact, based on this research, the related oil spill has a very contrasting tone compared to the surrounding water and this section has a straight and linear shape and is adjacent to the Central Plant F/S. The oil spill data released by LAPAN is assumed to only focus on detecting oil spill around the YYA-1 platform area, so that the dark spot area close to Central Plant F/S is not mapped.

In Table 2, it can be seen the area comparison between the oil spill from this research and LAPAN data as well as the percentage of the confirmed oil spill between this research and LAPAN data. The area difference that occurred was mainly due to the oil spill around Central Plant F/S which was not mapped in the LAPAN data and the differences in the oil spill boundary between the two data.

Another verification is performed using additional information such as news. Based on the data processing, the oil spill reached the coast on the imagery on August 23, 2019 and September 4, 2019, precisely, Sedari Village and Cemarajaya Village. This was supported by online media news that wrote that the oil spill reached Sedari to Cemarajaya Coast, Karawang (Kompas.com, 2019) and Pertamina news release itself (Pertamina, 2019a). The oil spill that scattered on the coast, at some points melted like flowing oil. In addition, according to Jabarnews (2019), the oil spill caused by PHE ONWJ oil platform also has reached Sedari Village, Karawang Regency, and cleaned up by hundreds of fishermen around the coastline area of Karawang.

CONCLUSIONS

The spread of oil spill due to oil and gas exploration activities in Offshore Karawang from July to September 2019 was successfully detected using Sentinel-1 data. It can be said that Sentinel-1 utilization in this study managed to map the oil spill properly and effectively in the term of time and cost. Its wide coverage also allows the detection of oil spills on the different platforms.

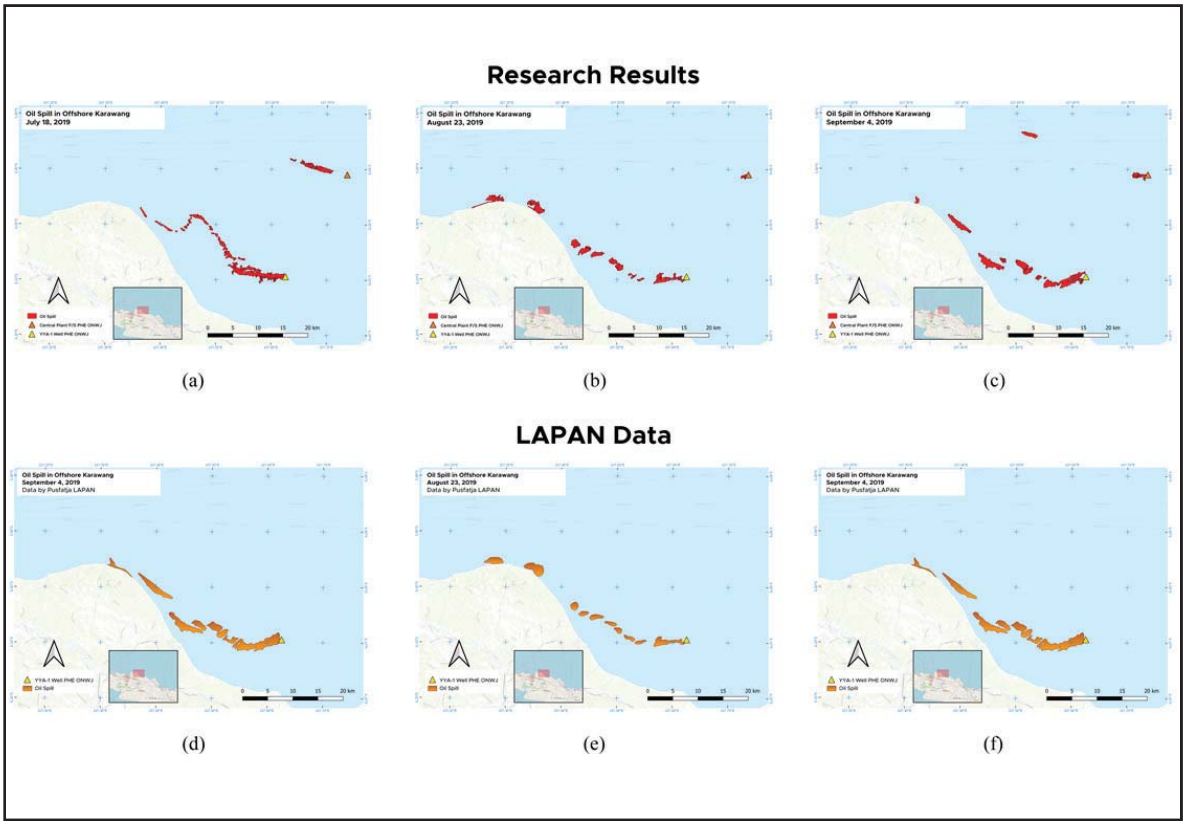

Figure 7
Comparison of this research to LAPAN data. This research: (a) July 18, 2019, (b) August 23, 2019, (c) September 4, 2019, LAPAN Data: (d) July 18, 2019, (e) August 23, 2019, (f) September 4, 2019.

Based on the data processing, the detected oil spill was spread into two main groups, specifically the oil spill that spread from the YYA-1 platform and the oil spill that spread from the Central Plant F/S. The area of the oil spill detected from the Sentinel-1 data on July 18, 2019, August 23, 2019, and September 4, 2019, were respectively 24.79 km^2, 20.05 km^2 and 27.12 km^2. The oil spills tend to shift westward from July to September 2019. This shifting is supposed to be influenced by current and wave factors that were dominant moving westward at that time.

ACKNOWLEDGEMENT

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GLOSSARY OF TERMS

Symbol	Definition	Unit
F/S	Floating Storage	
GRD	Ground Range Detected	
IW	Interferometric Wide-swath	
LAPAN	Lembaga Penerbangan dan Antariksa Nasional (National Aeronautics and Space Agency)	
PHE ONWJ	Pertamina Hulu Energi Offshore North West Java	
SAR	Syntethic Aperture Radar	
SNAP	Senintel Application Platform	

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