Oil Spill Detection by Sentinel-1 SAR Data

Nguyen Duc Loc[1], Shashi Kumar[2], C.M.Bhatt[3], Tran Trong Phuong[1]

[1]Department of Surveying and Mapping, Vietnam National University of Agriculture
[2]Photogrammetry and Remote Sensing Department, Indian Institute of Remote Sensing
[3]Disaster Management Studies, Indian Institute of Remote Sensing

Abstract

This paper aims to demonstrate the potential of space-borne Sentinel-1 SAR data for oil spill detection in the coast of Chennai (India). A dual polarization (VH, VV) Sentinel-1 SAR satellite data was used to map the extent of spill. After pre-processing of the data, oil spill area was detected using two approaches: adaptive shift threshold and object-based classification by contextual information. Results showed that three parameters: Background Window Size = 500, Threshold Shift = 3dB and Minimum Cluster Size = 1km^2 are the best suitable for detecting oil spill by adaptive shift threshold approach. However, the drawback of this method was indistinguishable from oil spill and look-alike features. It was overcome by object-based classification method with the support of contextual information, such as collision location, ships location, wind direction, current direction.

Keywords: *contextual information, detection, oil spill, Sentinel-1, SAR.*

1. Introduction

An oil spill is a release of a liquid petroleum hydrocarbon into the environment due to human activity; the term often refers to marine oil spills. Oil spills include releases of crude oil from tanker ships, directly from accidents and indirect from ship operations, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum products, such as gasoline, diesel and their by-products and heavier fuels such as bunker fuel used by large ships, or the spill of any oily white substance refuse or waste oil.

Optical remote sensing can be used for the application of oil-spill detection. Zhao et al. (2014) utilized the spectral signature in the optical and infrared domains to investigate oil slicks in shallow coastal waters of the Arabian Gulf by MODIS, MERIS and Landsat data. Two object-based image analysis methods are developed by Polychronis & Vassilia (2018) to detect oil spills along the south coast of Athens (Greece) using Sentinel-2 imagery. However optical data are often unavoidably suffered from weather and light conditions. For example during the Qingdao oil pipe accident that took place in November 2013, crude oil flowed into the bay through drainage channel. Heavy smoke caused by the explosion covered the whole scene, which largely hampers the application of optical based sensors. Moreover there are also a lot of oil-spill accidents takes place during night or stormy weather. Due to the advantage of wide areal coverage under all-weather conditions the imaging capability during day-night times, satellite synthetic aperture radar (SAR) data from ERS-1/2, ENVISAT, ALOS, RADARSAT-1/2, TerraSAR-X and Sentinel-1 have been widely used to detect and monitor oil-spill. Konstantinos & Apostolos (2012) used decision tree forest to select and classify oil spill from 24 high resolution SAR images from the European Remote Sensing Satellite 2 (ERS-2) SAR image data. Based on visual interpretation of radar images from ASAR ENVISAT, Alexander Holstein et al. (2018) detected 329 oil slicks in Kazakhstan sector during the years 2005-2012. Sentinel-1 SAR imagery was utilised to map the oil spill of Balikpapan Bay by Ratna Prastyani (2018). Airborne SAR sensors like Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR, by JPL, L-band) and E-SAR, (by DLR, multi-land) have also proven their potential for scientific research of marine or land remote sensing. Jones and Holt (2018) indicated that high resolution L-band SAR data acquired from Uninhabited Aerial Vehicle SAR (UAVSAR) could be used for oil spill response. Peng Liu at al. (2011) compared two ocean oil spill detection approaches based on four scattering matrices measured by fully polarimetric synthetic aperture radar (SAR) with L-band fully polarimetric UAVSAR data acquired during the Deepwater Horizon oil spill disaster event in the Gulf of Mexico in the year 2010. With a series of key breakthroughs of SAR remote sensing technology, especially the multi-polarimetric capability and increased resolution, oil-spill detection by SAR has become a very hot research area.

In the early morning of January 28, 2017, a liquefied petroleum gas tanker, the BW Maple, while coming out of the Kamarajar port, Ennore (Chennai, India), collided with another tanker, the MT Dawn Kanchipuram, laden with 32,813 tonnes of petroleum lubricant. As per the real-time data of Port's Vessel Traffic Management System (VTMS), the Maple crashed into the side of the Dawn Kanchipuram at about 3.45 AM, leaking dark waxy bunker oil of the latter into the sea at about two nautical miles from the coast. According to the published reports (ICMAM, 2017), the hull of the ship Dawn Kanchipuram was ripped, damaging the ship's accommodation as well as the pipelines on the deck and the water ballast tank on the outer surface of the LPG tanker BW Maple. As reported by various media nearly 70 tonnes of oil sludge accumulated on the Ennore shore at Ramakrishna Nagar Kuppam beach and was removed by the Indian Coast Guard and the local volunteers. Finally, it has been estimated that 196 MT of bunker fuel oil was spilled during this incident.

2. Materials and Methods

2.1. Materials

C-band Sentinel-1 SAR data and the ocean conditions on 29/01/2017 were utilized for oil spill detection and discrimination from look-alike feature.

Field data collected from ICMAM (2017) report are used for accuracy assessment.

Table 1. Field data in 29/01/2017 collected from ICMAM (2017) report

Location	Latitude (N)	Longitude (E)	Note
Thiruchanakuppam	13°08′58.11″	80°18′12.51″	Nearshore
Tiruvottiyur	13°10′10.98″	80°18′41.84″	Nearshore
Nettukuppam coast	13°13'42.25"	80°19'49.80"	Nearshore
Kasi Koil Kuppam	13°11'19.03"	80°19'02.31"	Nearshore
Bharathi Nagar	13°11'03.95"	80°19'01.28"	Nearshore
Radha Krishna Nagar Kuppam	13°09'21.04"	80°18'21.12"	Nearshore

2.2. Methods

The methods include initial preprocessing, oil spill extraction based on backscatter value, H/A/Alpha decomposition, oil slick extraction based on object-based classification. An overview of the methodology followed for this research is depicted in Figure 1.

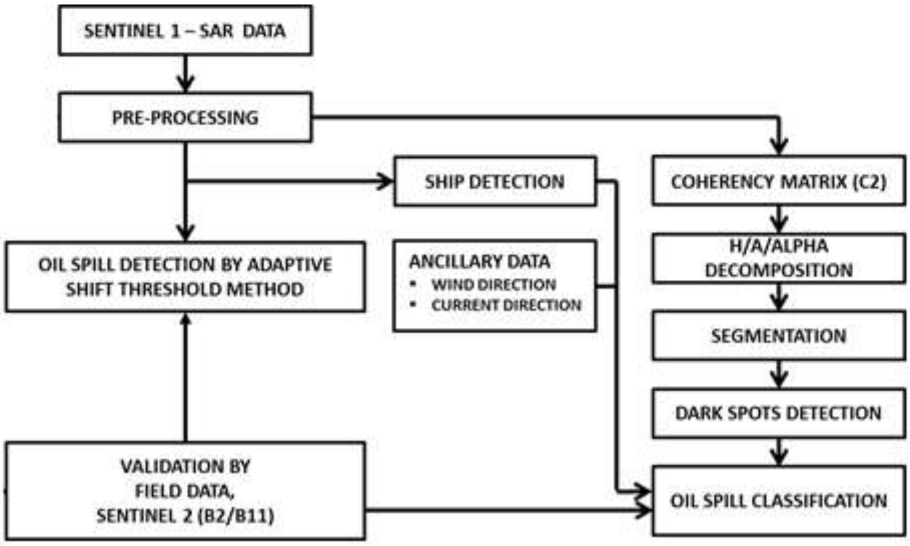


Figure 1. Methodological Flow Diagram

2.2.1. Pre-processing includes following steps: Split, radiometric calibration, debrust, multilooking and filter.

2.2.2. Oil spill Detection by Adaptive Shift Threshold

The oil spill detection operation consists of the following two operations. Firstly, dark spots are detected in this step with an adaptive thresholding method. Then, pixels detected as part of the dark spot are clustered and then eliminated based on the dimension of the cluster and user selected minimum cluster size.

2.2.3. Segmentation and Feature extraction

After H/A/Alfa decomposition was implemented, three output layers: Entropy, Anisotropy, Alpha were utilized as input layers for segmentation.

Two features related to shape are area and length to width ratio were used as main keys to extract oil slicks and eliminate look alike features.

3. Results and Discussion

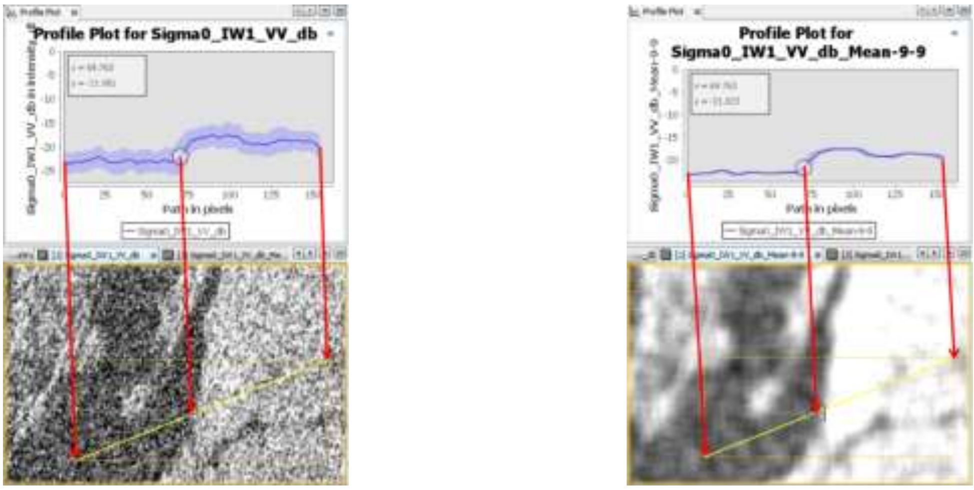
3.1. Radar backscatter coefficient value of oil slick and water

The most important parameter for oil detection is backscattering coefficient (sigma nought σ^0). The more different between oil slick and water, the easier to detect oil from sea surface. Table 2 showed the backscattering coefficient value of water and oil spill before and after filter. Before filtering, the mean value of water was -18.3dB while the average value of possible oil spill was -22.1dB. After filtering, the average value of water was -18.5dB and the average value of possible oil spill was -22.0 dB.

The difference of sigma nought value before and after implementing filter were 3.8dB and 3.5dB respectively. Although the difference between them is marginal (0.3dB) but the profile plot of sigma nought value after filtering (Figure 2) revealed that filtering enhanced the homogeneity of water and possible oil slick and it is helpful for improving the accuracy of oil slick detection.

Table 2. Backscattering coefficient value of water and oil spill before and after filter (dB)

	Before filter		After filter	
	Water	Possible oil spill	Water	Possible Oil spill
Highest	-17.3	-20.9	-17.5	-21.0
Lowest	-19.3	-23.2	-19.5	-23.0
Mean	-18.3	-22.1	-18.5	-22.0
$\boldsymbol{\sigma^0_{water} - \sigma^0_{Oil\ spill}}$	3.8		3.5	



a) b)

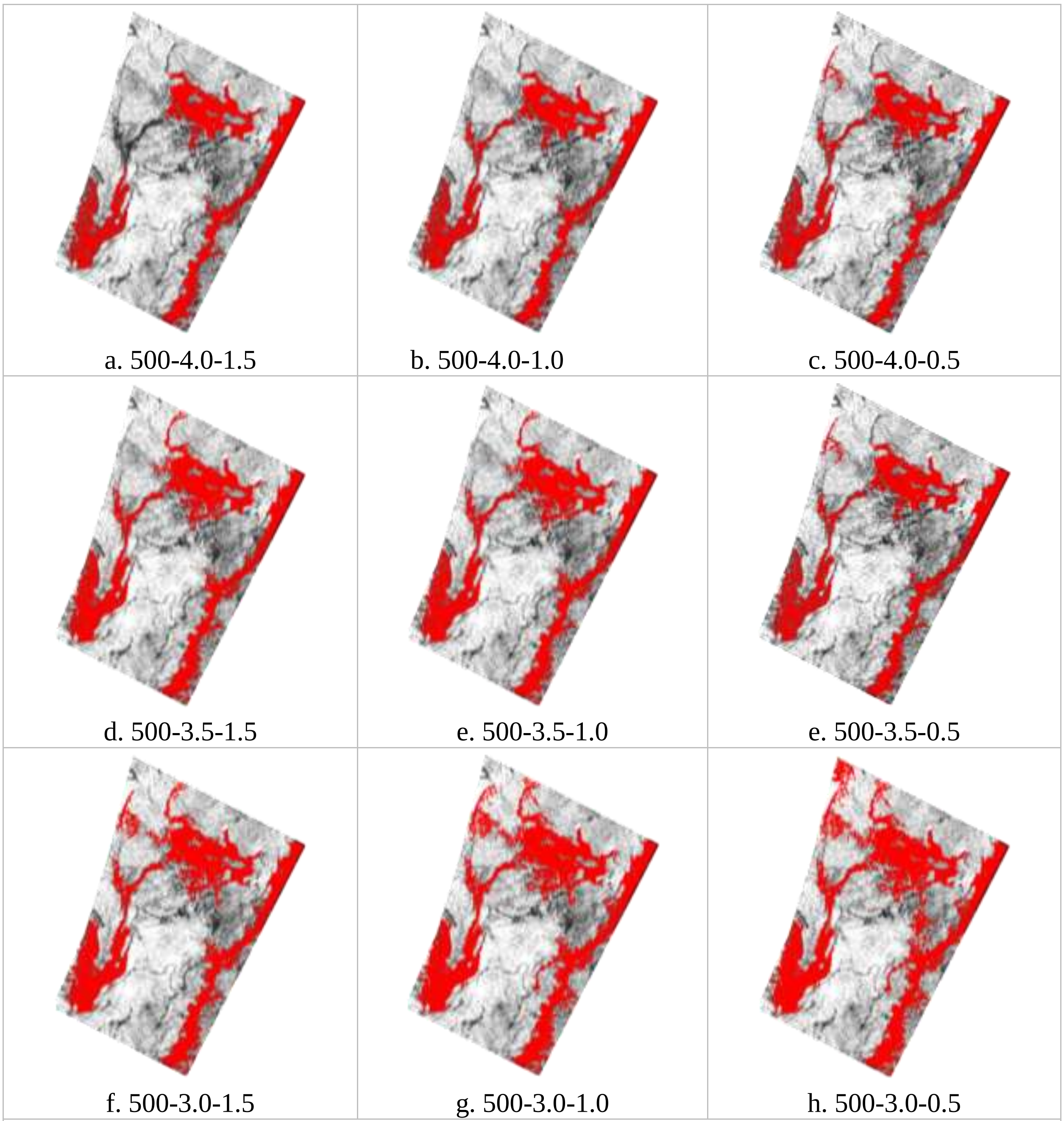
Figure 2. Backscattering coeficient value of oil slick and water before (a) and after (b) filtering

3.2. Oil spill detection by Adaptive Shift Threshold

In this method, dark spots are detected using an adaptive threshold algorithm where the local mean backscatter level is estimated using pixels in a large window. Then, a threshold is set to 'k' decibel below the local mean calculated before. Pixels within the window with values lower than the threshold are detected as dark spot. Finally, the detected pixels are clustered into a single cluster and those with sizes smaller than a predefined size selected by the user are eliminated. So three input parameters are utilized for detecting possible oil spill: Background window size, Threshold shift (dB) and Minimum cluster size (km^2).

To find out the suitable input parameter set for oil slick detection in the study area, nine experiments were implemented. The background window size was remained constant while the threshold shift was set by 4.0dB, 3.5dB, 3.0dB and minimum cluster was set by 1.5km^2, 1.0 km^2, 0.5 km^2. Results in figure 3 revealed that when the minimum cluster size was reduced from 1.5 km^2 to 0.5 km^2, the number of pixel was assigned as possible oil spill was increased. Likewise, if the shift threshold was decreased from 4.0dB to 3.0dB, the area of possible oil slick would be expanded.

The least possible oil spill area was generated by the input parameter set 500-4.0-1.5. While the largest possible oil slick was created by the input parameter set 500-3.0-0.5. The pair input parameter set 500-3.5-1.5 versus 500-3.5-1.0 and 500-40-0.5 versus 500-3.5-0.5 produced the same results. The best result was given by input parameter sets 500-3.5-1.5 and 500-3.5-1.0. This agreed completely with the analysis of radar backscatter coefficient value between oil slick and water in section 3.1.



a. 500-4.0-1.5 | b. 500-4.0-1.0 | c. 500-4.0-0.5

d. 500-3.5-1.5 | e. 500-3.5-1.0 | e. 500-3.5-0.5

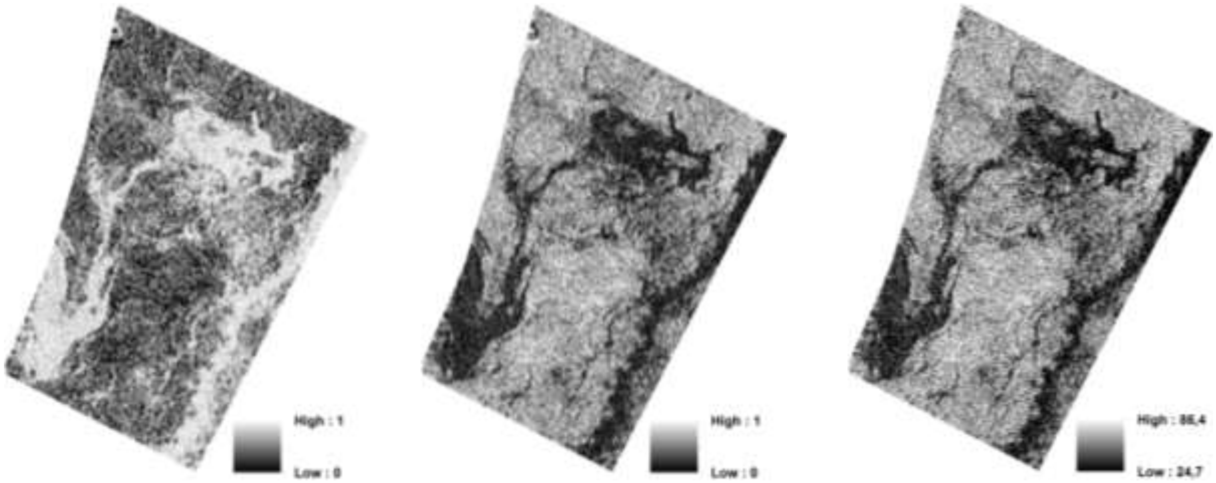
f. 500-3.0-1.5 | g. 500-3.0-1.0 | h. 500-3.0-0.5

Figure 3. Possible oil spill detected by Adaptive Shift Threshold

3.3. H/A/α decomposition

Polarimetric SAR is an advanced imaging radar system and plays an important role in radar remote sensing. With a polarimetric SAR, we can obtain much more information than single polarized SAR systems. After calibration of the polarimetric SAR and image speckle filtering, feature extraction is the key step for target detection and target classification. An important approach to feature extraction is target decomposition. It is to decompose a scattering matrix or a covariance matrix to the linear combinations of some special typical scattering, such as the single bounce scattering, the double bounce scattering, and the volume scattering. The important decomposition includes Krogager's decomposition, Cloude-Pottier H/A/Alpha decomposition, Freeman-Durden's decomposition, Yamaguchi's decomposition.

Figure 4 showed the results of H/A/α decomposition. It was observed that possible oil spill appeared white in Entropy, appeared dark in Anisotropy and Alpha. Alpha value of the possible oil spill is from 24.7° to 54° while its value of water is from 54° to 86.4°. The entropy value is high for oil slicks and low entropy value of sea surface. Figure 4 shows that the calculated Entropy values ranges from 0.86 to 1.0 for oil slick covered area and less than 0.86 for sea surface. Anisotropy value of sea surface (from 0.38 to 1) is greater than its in oil spill area (from 0 to 0.38). So it can be concluded that H/A/α decomposition is useful for distinction possible oil slick from sea surface but it could not differentiate oil slick from look-alike features.

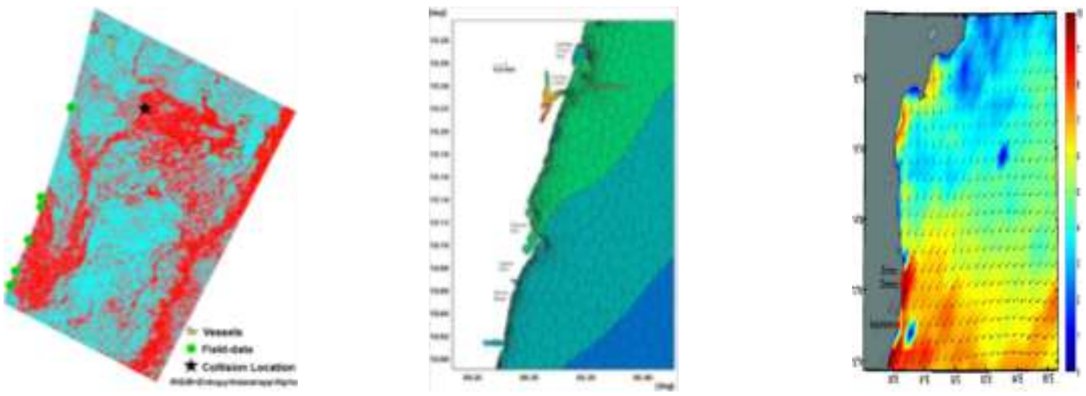


a. Entropy b. Anisotropy c. Alpha

Figure 4. H/A/Alpha decomposition

3.4. Differentiation oil spill from look-alike features by combination of object-based classification and contextual information

The above method based on backscatter coefficient value of VV polarization of C-band Sentinel-1 SAR were useful for discrimination between possible oil slick and sea surface but they could not differentiate between oil spill and look-alike features. In this case, to distinguish oil spill from look-alike features, contextual information becomes usefully. Based on the location of ship collision, north-east direction of wind and south direction of current, it could be interpreted that the dark patch in the left of image is oil spill. It was comfirmed by the field data. Three vessels in the north of this patch could be rescue ships which were cleaning oil from the sea.



a. Location of collision, vessels location and field data | b. Current vector | c. Wind direction and wind speed

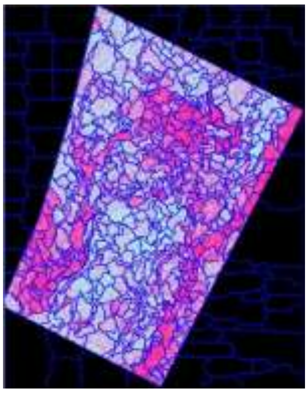
Figure 5. Contextual information

Object-based classification method was utilized to separate oil spill from look-alike features. Input data for classification was generated by the combination of H/A/α. First step for object-based classification is segmentation. The parameters for this step were: Image Layer Weights = 1:1:1, Scale parameter = 10, Shape = 0.1, Compactness = 0.5. The result was shown in figure 6a.

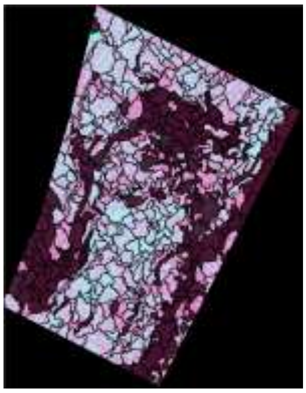
The second step is dark spot extraction (or possible oil spill extraction). Based on the analysis in section 3.3, dark spot was extracted by conditions: Mean layer 1 (Entropy) > 0.86, Mean layer 2 (Anisotropy) < 0.38 and Mean layer 3 (Alpha) < 54. The result was represented in figure 6b.

In third step, all dark segment stay next to each other was merged. The result was shown in figure 6c.

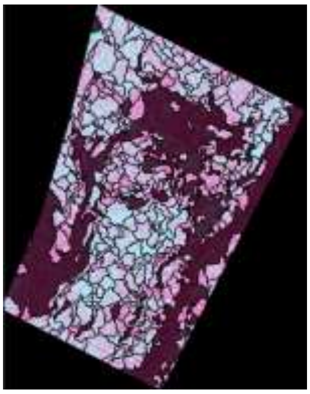
Last step is discrimination oil spill and look-alike features. To eliminate the dark patch in the right of image and the small dark segment spreaded out, two conditions were utilized: Length/Width < 3 and Area > 1.0km^2. The final result was shown in figure 6d.



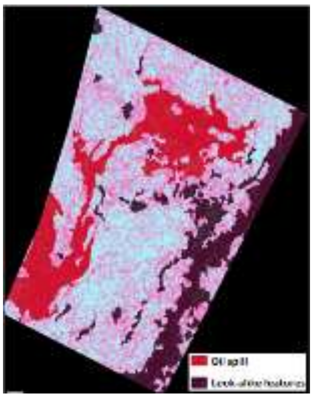
a. Result of Segmentation



b. Result of dark spot extraction



c. Result of merge



d. Oil spill classification result

Figure 6. Object-based classification results

4. Conclusions

Oil spill has low backscatter coefficient value ($\sigma^0_{oil} = -22dB$) while sea surface has higher backscatter coefficient value ($\sigma^0_{water} = -18.5dB$).

Adaptive Shift Threshold method was implemented by threshold value was -22dB and shift threshold was 3.5dB. This approaches has ability to detection possible oil slicks but could not differentiate them from the look-alike features.

Contextual information such as the location of ship collision, wind direction, current direction, vessels location were useful for differentiation between oil slicks and look-alike features.

It is not difficult to detect oil spill by C-band SAR data but discrimination oil from look-alike is a challenging task. Ocean condition information at the time satellite data acquired is very useful to differentiate and identify what are look-alike features.

References

Alexander Holstein, Martin Kappas, Pavel Propastin, Tsolmon Renchin (2018). Oil spill detection in the Kazakhstan sector of the Caspian Sea with the help of ENVISAT ASAR data. Environmental Earth Sciences 77:198.

ICMAM (2017). Ennore Oil Spill (Chennai Coast), the Ecological Footprint - An Assessment.

Jones, C.E.; Holt, B. (2018) Experimental L-Band Airborne SAR for Oil Spill Response at Sea and in Coastal Waters. Sensors , 18, 641.

Konstantinos Topouzelis, Apostolos Psyllos (2012). Oil spill feature selection and classification using decision tree forest on SAR image data. ISPRS Journal of Photogrammetry and Remote Sensing 68 135–143

Peng Liu, Xiaofeng Li, John J. Qu, Wenguang Wang, Chaofang Zhao, William Pichel (2010). Oil spill detection with fully polarimetric UAVSAR data. Marine Pollution Bulletin 62 2611–2618

Polychronis Kolokoussis and Vassilia Karathanassi (2018). Oil Spill Detection and Mapping Using Sentinel 2 Imagery. Journal of Marine Science and Engineering.

Ratna Prastyani, Abdul Basith (2018). Utilisation of Sentinel-1 SAR Imagery for Oil Spill Mapping: A Case Study of Balikpapan Bay Oil Spill. Journal of Geospatial Information Science and Engineering .

Zhao, J., Temimi, M., Ghedira, H., & Hu, C. (2014). Exploring the potential of optical remote sensing for oil spill detection in shallow coastal waters-a case study in the Arabian Gulf. Optics Express, 22(11), 13755. doi:10.1364/oe.22.013755