

THE USAGE OF RADAR IMAGES IN OIL SPILL DETECTION

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ABSTRACT:

Discharge of oil including with the tanker accidents have the most dangerous and hazardous effects on marine environment. It is specified that annually more than 4.5 million tons of oil based disposals are poured out to the sea worldwide. The main waste source is the ship based operational discharges with an approximate %45 percentage. The world's %28 petroleum transfer passes through Mediterranean which makes the %50 of all the transfers in Mediterranean as risky and dangerous. Therefore Turkey, with its surrounded coasts and heavy tanker traffic, is under risk of petroleum hazard. An oil spill monitoring and detection system should be used to prevent and interfere immediately. In order to interfere the oil spill, it is important to identify the type, aerial extent, position, (nearest ship position if any), the possibility percentage etc. For this purpose, satellite-based oil pollution monitoring systems are being used to take precautions and even to determine the possible polluter. Today, Synthetic Aperture Radar (SAR) satellites are the main data sources to detect the oil spills discharged into the sea with sufficient accuracies. In this study, the advantages and disadvantages of using different radar images for oil spill detection in Marmara Sea were investigated.

1. INTRODUCTION

In the context of oil spill pollution in the seas, the development and increase of overseas transportation are an important factor both socially and economically. The harmful effects of marine pollution are numerous, from global climate changes to the damage of the aquatic ecosystem. As such, the need for oil slick detection is crucial, for the location of polluted areas and to evaluate slick drift to protect the coastline. Satellite-based oil spill monitoring system that can be used to take precautions and even to determine the possible polluter, has a vital importance on the detection and protection of national and international waters from the possible damages of petroleum hazard.

The %30 of international marine trade takes place among the ports of Mediterranean and nearby seas. Every year nearly 20.000 tons of petroleum leaks to Mediterranean from the surrounded 60 oil refining plants as a result of consciously or unconsciously accidents (Günel, 2004).

In previous studies done using satellite (Envisat) images acquired over Mediterranean Sea, it's been observed that more than one third of the images have different levels of oil discharge (Pavlakis et al. 2001). Therefore monitoring these risky areas is highly significant to prevent any possible disasters.

Turkey is surrounded by three main Seas and the tanker/vessel traffic is intensive due to being on important trading routes of Mediterranean. The coastlines of Mediterranean Sea, Aegean Sea, Marmara Sea including the Bosphorus and Dardanelle straits are among the most effected shores of Mediterranean basin depending on the Barcelona Convention. Especially, the straits have an ecological and economical role while the vessels transporting petroleum and trading products through northern countries to the rest of the world pass by. For example, in 2001, 101 million ton petroleum products have passed through Bosphorus. Turkey is the tenth country listed as the most tanker accidents occurred (Kasap, 2002).

Satellite images improve the possibilities for the detection and monitoring of oil spills as they cover large areas in all weather

conditions and offer an economical and easier way of continuous coastal areas patrolling. Satellite monitoring, in particular using Synthetic Aperture Radar (SAR) observations; represent an effective tool beside traditional aerial surveillance and extensively used for the identification of oil spills in the marine environment.

The capability of SAR in detecting oil slicks over the sea surface is well known and proven by several studies aiming at oil spill detection using SAR images (Martinez and Moreno, 1996; Ziemke, 1996; Kubat et al., 1998; Benelli and Garzelli, 1999; Lu et al., 1999; Solberg et al., 1999; Del Frate et al., 2000; Gade et al., 2000; Topouzelis et al., 2002; Topouzelis et al., 2007). Most of these studies primarily based on the detection of dark spotted areas. In SAR images any dark spotted area that has high contrast relatively to its surrounding should be examined in case of any oil spill discharge possibility.

Natural dark patches are termed oil slick look-alikes. Oil slicks may include all oil related surface films caused by oil spills from oilrigs, leaking pipelines, passing vessels as well as bottom seepages, while look-alikes do include natural films/slicks, grease ice, threshold wind speed areas (wind speed <3 m/s), wind sheltering by land, rain cells, shear zones, internal waves, etc (Espedal, 1998). Because of this, further classification of the dark areas as oil spills and look-alikes is therefore required.

In major case of discharged oil to the seas the detection and monitoring of the oil spills have critical importance for rapid emergency response activities. These should cover four basic issues; *i*) prevention *ii*) alarm, *iii*) monitoring and *iv*) damage quantification (Bava et.al, 2002). Whatever its source is, oil spill pollution will continue to occur, therefore, in order to lessen its effect, the improvement of its detection and continuous monitoring are the most important issues to effectively plan countermeasures responses.

In this study, the Marmara Sea, highly risky area, was selected as the study area. Seven radar images were analyzed visually and digital image processing techniques such as filtering and

textural applied in order to discriminate and assign possibility of being an oil discharge.

2. STUDY AREA AND DATA USED

2.1 Study Area

Bosporus, the main strait that forms the boundary between Europe and Asian part of Turkey, is the world's narrowest strait used for international navigation. In more recent years, the Turkish Straits have become particularly important for the oil industry. Russian oil, from ports such as Novorossiysk, is exported by tankers to Western Europe and the U.S. via the Bosporus and the Dardanelles straits.

Depending on the Barcelona Convention and the importance of straits, Marmara Sea was chosen as the study area (Figure 1).



Figure 1. Map of the study area

2.2 Data Used

Regarding to the study area 7 Radarsat-1 satellite images belonging to different image segments and passes were used (Table 1). The images were SGF type CEOS formatted products that were geometrically corrected based on satellite ephemeris and acquired by ITU-CSCRS (Istanbul Technical University – Center of Satellite Communication and Remote Sensing).

Some meteorological data (such as wind speed) at the times of the images acquired were used as ancillary data. Flow direction and flow rate information that are very important for the detection of illegal oil discharge with radar imagery couldn't be used due to unavailability of measurement stations for systematic observation.

Acquisition Date & Time	Beam mode	Incidence angle
18.08.1999 – 15:58	S3	34°
04.10.2002 – 04.01	F	44°
08.07.2004 – 16:04	S6	44°
09.10.2004 – 15:51	S2	27°
14.05.2004 – 16:10	S7	47°
17.05.2003 – 15:56	W2	35°
26.11.2004 – 15:51	S2	27°

Table 1. The characteristics of the radar dataset used

3. METHODOLOGY

In this study, both visual and digital image processing techniques were applied. The methodology used is shown in figure 2 and the details are given in following sections.

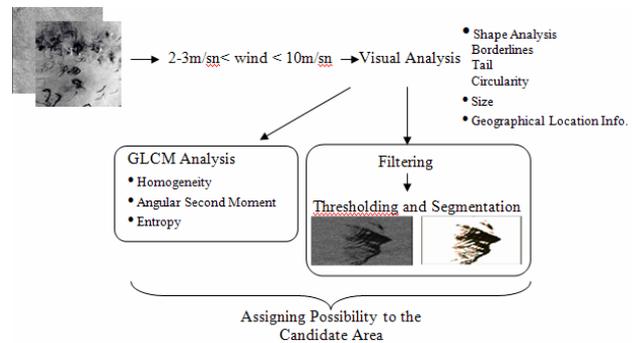


Figure 2. Flow chart of the study

3.1 Visual Analysis

Illegal oil discharges in the marine environment will immediately start to spread, dispersed or degenerated by natural processes that are collectively called weathering over time. The progress, duration and result of the weathering processes depend on the amount, composition and properties of the spilled oil. Illegal oil slicks are relatively thin and small in size and they are therefore easier degenerated by weathering in comparison with hazardous accidental oil spill. Environmental conditions such as mixing, currents, temperature and sunlight are also important for the weathering of spilled oil. (Maar et al, 2003)

Because of weathering processes that dominate impact on the spill during the first few hours after dumping, to detect the new oil spills are the most important ones for the detection. Large amounts of oil will result to large spills, usually within a short time after dumping. On the other hand oils with large volatile and dissoluble in seawater content will result to smaller spills, in comparison to those with less such content, when spilled in the same amounts (Pavlaklis, 2001).

In simulation done by Hollinger and Mannella in 1984 for the spills from a ship discharging on a 15 knots straight course, an amount of 7 tons of fuel oil just at the end of discharging and 2 hours after discharging assuming calm and current free weather with 0.6 m²/sec spreading rate can be observed in Figure 3a and 3b. On the other hand if there was a spill shape distortion due to current filed the observations one and three hour after discharging would be as shown in Figure 3c and 3d.

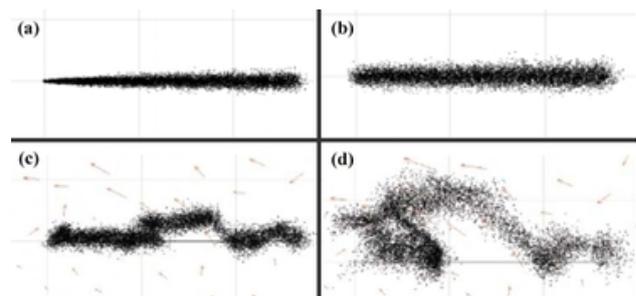


Figure 3. Simulations of oil discharge (Hollinger, 1984)

Weathering processes aren't the only cause that effects the detection of oil spill with radar satellite imagery. But also the look-alike phenomena that appears under sea-air boundary layer conditions may be classified as oil spill in radar images. These may include, natural slicks threshold winds, wind shadows behind islands, winds slicks (calm zones), surface currents, internal waves, reflections of the bottom topography in shallow waters, fresh water slicks, plums of municipal sewage, wave shadows behind land or structures, weed beds that calms the water just above them, glacier flour, biogenic oils, and whale and fish sperm (Bava, 2002) (Figure 4).

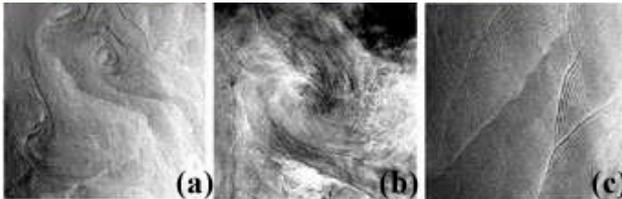


Figure 4. Example of look-alikes observed by ERS; (a) and (b) eddies, (c) internal waves (Gagliardini, 2004)

3.2 Filtering

Adaptive filtering methods are used to discriminate high contrast areas representing possible oil discharges in the images. In general Lee (7x7), Gamma (7x7), Frost (7x7) and two pass (3x3 median filter + 5x5 low pass filter) filters are used in different oil spill discrimination studies (Marghany, 2001; Özkan, 2007). It is also observed that these filters minimize the loss of information boundaries of high and low contrasted areas.

3.3 Thresholding and Segmentation

In segmentation neighboring pixels are compared and they are merged into regions if they are similar. It runs iteratively to merge the resulting regions. Two neighboring regions, R_i and R_j , are merged if they satisfy the following conditions:

- Thresholding condition: $\text{dist}(R_i, R_j) \leq T$,
- Neighborhood condition 1: $R_j \in N(R_i)$ and $\text{dist}(R_j, R_i) \leq \text{dist}(R_k, R_i)$, $R_k \in N(R_i)$,
- Neighborhood condition 2: $R_k \in N(R_i)$ and $\text{dist}(R_i, R_j) \leq \text{dist}(R_k, R_j)$, $R_k \in N(R_j)$

In the above, T is the chosen similarity threshold, $\text{dist}(R_i, R_j)$ is the Euclidian distance between the mean grey levels of the regions and $N(R)$ is the set of neighboring regions of region R . Also, regions smaller than the chosen area threshold are removed by merging them with its most similar neighbor (Espindola et al, 2006). The results of the segmentation algorithm are sensitive to the choice of similarity and area thresholds.

3.4 GLCM Analysis

Texture is a combination of repeated patterns with a regular frequency. Texture analysis is defined as the classification or segmentation of textural features with respect to the shape of a small element, density and direction of regularity. In this context, grey level co-occurrence matrices (GLCM) are used as a specified texture measure.

GLCM is a square matrix which has the same number of rows and columns as the quantization level of the image and symmetrical around the diagonal. It considers the relation between two pixels at a time, called the reference and the neighbor pixel. The aim of this method is to characterize the stochastic properties of the spatial distribution of gray level in an image.

Most texture calculations are weighted averages of the normalized GLCM cell contents. The result of a texture calculation is a single number representing the entire window. Texture measures are divided into groups according to the purpose of the weights in the equations. Contrast group measures such as Contrast, Dissimilarity and Homogeneity (Inverse Difference Moment) use weights related to the distance from the GLCM diagonal. Measures related to orderliness such as Angular Second Moment, Energy and Entropy uses the normalized values (P_{ij}) of the GLCM matrix in some form as weight for themselves as it is the measure of commonness of occurrence. The third group is the descriptive statistics of GLCM texture measures which are GLCM Mean, Variance (Standard Deviation) and Correlation.

In this study, Homogeneity, Angular Second Moment and Entropy measurements were preferred since the efficiency of these measurements is shown in many studies (Assilzadeh and Mansor, 2001; Marghany, 2001).

Homogeneity measure weights pixel values by the inverse of the Contrast weight and the weights are being decreased exponentially away from the diagonal;

$$\sum_{i=0}^{N-1} \frac{P_{ij}}{1 + (i-j)^2} \tag{1}$$

Angular Second Moment (ASM) uses each P_{ij} as a weight for itself. High values of ASM occur when the window is very orderly.

$$\sum_{i=0}^{N-1} P_{ij}^2 \tag{2}$$

Entropy is the opposite of Energy which is the square root of ASM. The calculation of entropy depends on the assumption of $\ln(0)$ that is indefinable and $0 \times \ln(0)$ is equal to 0.

$$\sum_{i=0}^{N-1} P_{ij} (-\ln P_{ij}) \tag{3}$$

The texture analysis depends on window size. In this study the window size having 7 x 7 pixels was chosen as used in earlier oil spill studies with texture measurements (Marghany, 2001).

4. ANALYSIS AND RESULTS

Four images out of total seven were eliminated due to inappreciate wind speed. For the next step, three images belonging to the Marmara Sea were visually inspected in order to eliminate the images which have not contained any high contrasted (dark spots) areas representing sign of possible illegal oil discharge.

4.1 Visual Analysis

After visual high contrasted area inspection two images were found to be adequate for visual oil spill discrimination.

The first image selected was the one acquired on 09.10.2004. In this image lots of different high contrast areas were observed due to its geographical location and intense vessel traffic. The ships waiting at the entrance of Bosphorus observed with their bright appearance and different sizes (Figure 5).

Atmospheric fronts were observed at the eastern part depending on the atmospherical conditions. Beneath the fronts, the possible oil discharge was detected. The contrast difference of the area with its surrounding was very sharp and the area had a close shape. In addition, due to wind conditions, the spill seemed to be divided but depending on the shape it could also be a new discharge. However, this possible oil spill wasn't verified by the authorities.

The track of ships that were passing through the Marmara Sea also observed too (Figure 5). These high contrasted areas were thought to have very low possibility of oil spill. Besides, the direction of the ship observed in one end had same direction with the high contrasted area. However, the boundaries weren't sharp enough with the oil spills in literature

Wind shadow areas that are generally seen at coastal areas and mostly behind of islands were observed in the image (Figure 5).

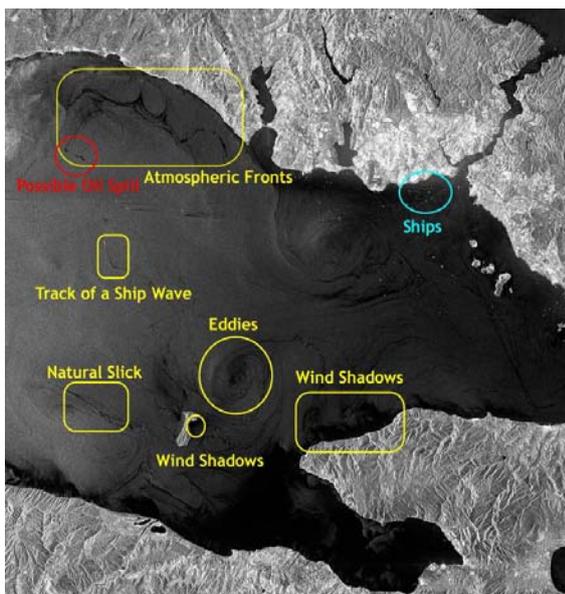


Figure 5. Visual analyses of the image acquired on 09.10.2004

In the visual analyses of the second image that was acquired on 26.11.2004, it's been observed that the high contrasted areas were the effect of rain cells.

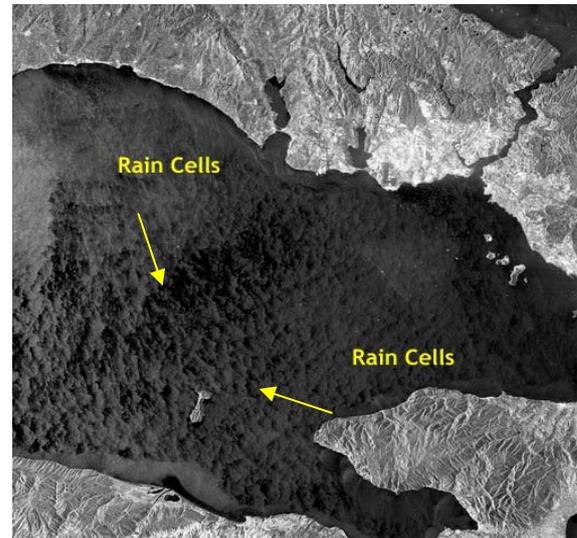


Figure 6. Visual analyses of the image acquired on 26.11.2004

The image acquired on 09.10.2004 was used in the next steps of the study.

4.2 Filtering

In the image selected, the possible oil spill was subsetted as 600 x 430 pixel area. This high contrast area was filtered with four chosen filters namely Lee (7x7), Gamma (7x7), Frost (7x7) and two pass (3x3 median filter + 5x5 low pass filter) filters (Figure 7).

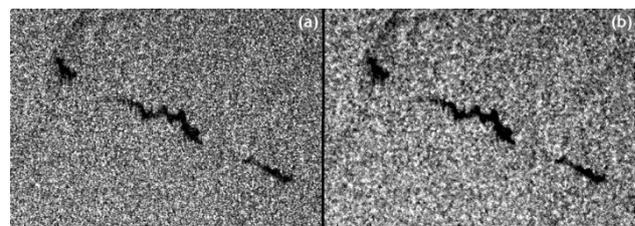


Figure 7. Possible oil spill; (a) the original image, (b) Lee filter applied image

4.3 Thresholding and Segmentation

After filtering process, thresholding and segmentation were applied to the selected image by choosing the adequate thresholding values (Table 2). Histogram based thresholding values were chosen in the segmentation process.

Filters	Threshold value
Lee	35
Frost	40
Gamma	43
Two pass	42

Table 2. The thresholding values for different selected filters

The results of the segmented areas representing oil spill (high contrasted areas) were vectorized and calculated as an areal extent (Table 3).

The analyses showed that the functionality of every filter depends on wind situation, the amount of oil discharged and duration of oil spilled.

Filters	Areal extent (km ²)
Lee	2.10
Frost	2.73
Gamma	2.82
Two pass	2.65

Table 3. Areal extent of high contrasted areas

It was observed that Gamma filter has given better results in the spread areas of the spilled oil. Besides, two pass and Frost filters gave sufficient results in the areas where the oil was mostly in linear form (Figure 8).

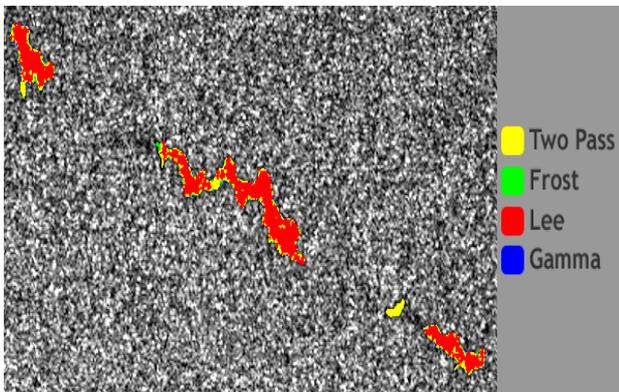


Figure 8. Comparison of different filters with possible oil spill in Marmara Sea

4.4 GLCM Analysis

Texture analyses were applied to the original image and analyzed as a second method because filters often average out most of the texture in an image. In this study, the neighbor pixel was chosen to be the one to the east (right) of each reference pixel.

Homogeneity measurement was selected in order to calculate the areas that have max. homogeneity. Entropy and angular second moment measurements were used to calculate the orderlineless and disorder respectively. The aim of choosing these measurements were to calculate the areas that has max. orderlineless and min. disorder. High contrasted areas representing oil spill, should have more homogeneity, less entropy and more second angular moment values regarding to its background.

The texture measurements were calculated and constituted as a data set for the selected image (Figure 9).

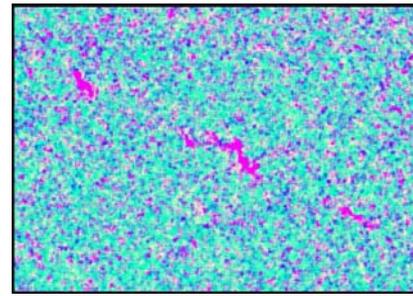


Figure 9. Textural data set of Marmara Sea for possible oil spill (R: Homogeneity, G: Entropy, B: ASM)

The data set classified with the Max. Likelihood algorithm. The training areas were chosen from the most homogeneous areas.

It was observed that the areal extension calculated from the classification of the possible oil spill was 1.18 km². By comparison the areal extent was found smaller than the other method and have better functionality with the oil spill within the less spread and mixed areas.

5. CONCLUSION

Remote sensing and satellite data are effective tools for man-made hazards like illegal oil spill discharges that need a synoptic view when there is an emergency status and where on site surveying is not possible. Another very important aspect of remote sensing is the production of the near-real time data by operational satellite-based monitoring systems so that authorities can quickly and directly use it. The main requirements of this system are the position of the possible oil spill and its probability level (i.e., low, medium or high).

Filtering, thresholding and segmentation techniques were applied and it's observed that every method was relatively effective in different cases. Among the filters used, Lee filter was the most effective one where the linearity was so distinct. On the other hand the others were effective on the spreading of oil spills.

As a second method, GLCM analyses such as homogeneity, entropy and angular second moment were used. It's observed that the results of texture analyses had compatible results with thresholding and segmentation techniques.

As shown in this study, space-borne SAR imagery can provide valuable information in monitoring and policing the marine-pollution problems. The suggested methods should be developed to establish operational oil spill monitoring system in order to protect the national and international waters of Turkey.

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