Detecting Oil Spills in the Offshore Nile Delta Coast Using Image Processing of ERS SAR Data

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Abstract: - Egypt, being one of the Mediterranean Sea basin countries, is highly concerned with the protection and preservation of the marine environment and the ecological integrity of its territorial waters and coasts. The Mediterranean is a fragile environment having an increasing international concern to minimize the degree of environmental stress resulting from marine pollution. The major source of pollution in this water body is the industrial waste water discharges. In addition, the accidental oil spills which usually results from collision of oil tankers, irrational dumping of bilge and ballast water from ships is considered as significant source of pollution within the Mediterranean Sea. Such pollution incidents cause serious damage to marine living resources and natural habitats. Early warning of oil spills can help planning intense monitoring schemes, formulating an effective protection measures and reducing the damages to the marine environment. One of the appropriate means for detecting a large sea area for oil spill is by Synthetic Aperture Radar (SAR) satellite data.

The present study is devoted to reliable detection, identification and classification of oil spills using different image processing techniques for ERS SAR data. This includes reception and processing of SAR raw data offshore Nile delta coast, analysis of these data and production of an interpreted oil spills. This has been done on three steps: (i) filtering and georeferencing of the raw data (ii) oil spills detection, identification and enhancement (iii) feature extraction (classification) in which oil spills are distinguished from other phenomena. The determination of environmental conditions (winds and sea currents intensities) gave a clear indication of what can be expected (i.e. predicting the moves of the oil spills). A total of eleven SAR images of high radiometric quality acquired within the period between February to July 2000 were processed. The number of identified cases was sixteen. The largest oil spill has a coverage area of about 186.66 km^2 on 23/5/2000. Several confirmed observations of these identified oil spills have been reported by the Egyptian Environmental Affairs Authority. The frequent satellite coverages of RADARSAT, ENVISAT and ALOS can be effectively used for continuous monitoring of the Egyptian territorial water for oil spills occurrences.

Key-Words: - Synthetic Aperture Radar (SAR) data, Oil spills, Image processing techniques, Nile delta coast.

1 Introduction

The general purpose of this study is to employ space-borne radar data and image processing techniques to detect and identify oil pollution in marine environment, especially in the offshore Nile delta coast of Egypt. Attention was focused on the area located to the eastern side of the Nile delta offshore water, between longitudes 30^o 25' E and 33^o 23' E, Latitudes 30^o 54' N and 32^o 25' N as shown in Fig. 1. The Suez Canal is the main international navigation route, between the Red Sea and the Mediterranean Sea, to transport the Arabian Gulf oil to Europe and USA. It is of major importance to have operative technique for detecting oil pollution in an effective way since it poses a serious threat towards coastal ecosystems, tourism and fishing. It has the immediate effect of killing an appreciable proportion of sea life. Influx of oil from tankers releasing ballast water, other oily water discharge and offshore oil platforms are major causes of marine pollution and havoc in the ecologically sensitive environment of semi-closed sea area. Such spills can impose a much greater threat than one big accident. In the sense, inflict more harm in the form of long term contamination of the food chain long after the cleanup operations needed to remove the damage.

In the last decade, SAR sensors have been broadly used for oil spill detection and monitoring in particular in deep oceans and offshore areas where field observations are limited. They have also provided excellent statistical information about small targets, as precise navigational accuracy for spills and sources as ships, tankers and platforms [1].

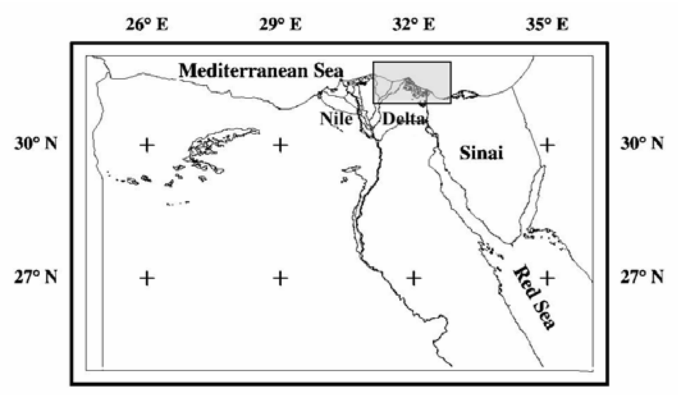

Fig. 1: Location map of the study area.

However, SAR data provide no clear discrimination of oil film thickness or type. Some very successful examples of ERS SAR applications in marine oil spill detection have been reported, such as; The Norwegian oil spill detection project [2], Monitoring oil spill pollution in the Mediterranean with ERS SAR [3], Oil pollution statistics in southeast Asian waters compiled from ERS SAR imagery [4], Sea surface observation using satellite imagery for marine environmental protection offshore United Arab Emirates [5] and Combined use of SAR and MODIS imagery to detect marine oil spills [6].

2 Data Acquisition

Hundreds of satellite images acquired and archived during the last decade over the study area constitute a substantial resource of data. They can provide a real scale of the oil spillage problem. SAR satellite sensors on board present and near-future satellites are the most suitable instruments for this purpose. The European Radar Satellites ERS-1/2 were successfully launched on 1991/1994 respectively. One of their main instruments onboard is the C-band (SAR) with 6 cm wavelength, VV polarization and an incidence angle of 23 degrees which provides images along swaths 100 km wide. This instrument produces a grayscale image which represents the radar backscatter from the ocean surface. Eleven ERS Medium Resolution Images (MRI) of SAR data (100 m resolution) were used in this study. The images were acquired within the period between February-July 2000. Quick-looks of some of these images are shown in Fig. 2.

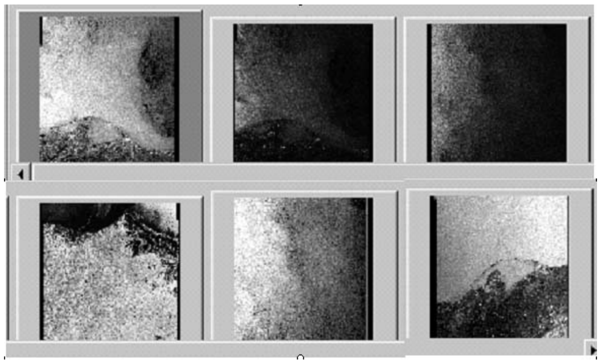

Fig. 2: Some quick-looks of the used ERS-MRI images of the study area.

The reliability of an analysis result is highly influenced by availability of the general sea state and weather measurements. Such as a 2 dimensional wave height, current direction and wind speed pattern. Because radar backscatter from the sea surface are strongly affected by these environmental factors, the ERS images used in this study were observed during suitable wind and sea state conditions for oil spill detection. Historical meteorological forecast data for corresponding images over the study area (prior to the time of the satellite's overpass) were obtained from a meteorological institute ICoD (Euro-Mediterranean Centre for Insular Coastal Dynamics), Valetta, Malta. This information was monitored on a regular grid, given by directions and intensities. All these elements are represented by vectors with appropriate symbols or colors, as depicted in Fig. 3, help users and experts in predicting the movement of the oil spills.

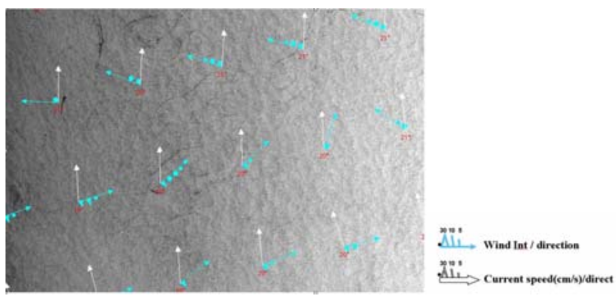

Fig. 3: Local observations of winds and marine currents over a part of the study area.

3 Background

Satellite-borne sensors have different electro-magnetic characteristics with varying limitation for detecting marine surface features. Reflectance contrast between clear water and oily water varies with sea water conditions at any given wavelength. SAR capability to acquire images of large areas of the earth's surface on a regular basis independent of solar illumination (day/night), cloud coverage and atmospheric conditions stimulated research programs to develop methods for accurate oil spills and ships detection [6]. It also yields different information than optical Infra-Red (IR) sensors. The suitability of radar imagery for oil spill detection is largely a function of the local weather and sea-state conditions at the time of image acquisition. For instance, a smooth sea surface appears dark and the brightness increases as the sea surface becomes rougher. Therefore, detection hinges on a significant difference in sea-surface texture (roughness degree) between the area covered by oil and the surrounding clean water.

Waves are induced by atmospheric effects and balanced by sea surface tension. Wind-generated short gravity-capillary waves reflect radar radiation creating a bright area in the radar image referred to as sea clutter [7]. Oil spills on the water's surface dampen these waves, and thus give reduced backscatter as smoother surfaces. Hence they appear dark against brighter surrounding areas in a SAR image. [8,9,10,11]. Generally the oil slicked surface shows a lower temperature than the surrounding clear water surface. The image data observed in night time is more reliable to avoid the influence of solar illumination difference between sea water and oil spills [5].

The visibility of oil spills on SAR images depends on the local wind speed, oil type and the age of the spill. At high winds, the oil may be washed down into the sea, and no surface effect is observed in the SAR image. At very low winds, no SAR signal is received from the sea, thus, no slicks can be seen. Under moderate wind conditions (2-10 m/s), oil layers will be detectable, [12,13]. Oil spills will not keep their location and shape for long periods due to dispersion also by other sea surface conditions such as waves and currents. One problem in detecting oil slicks on the sea surface lies in distinguishing oil from other phenomena that dampen out the short waves and create dark patches [14]. These phenomena could be wind shadow, organic matter such as algae bloom, local upwelling and shallow marine vegetation. However, a well trained user is in many cases able to discriminate between oil spills and other features. Since, usually oil slicks have relatively regular geometric shape than other marine surface features that could be recognized due to their distinctive configurations.

4 Methodology & Results

Image processing techniques and manipulation tools like filtering (convolution filters), georeferencing (incidence angle correction) and enhancement (modification of the look up table) have been used in this study. Moreover, vectorial meteorological data like wind, wave and current intensities, collected in real time as the acquisition time of the satellite data, could be overlaid on the image. Eleven MRI SAR images acquired during the period between February to July 2000, swathing an area of 100 km each, offshore Nile delta coast of Egypt were used. They cover the area to the north of Port Said governorate and the outlet of the Suez Canal which represents very dense ship traffic. The interpretation of the SAR images is the most important part of the image analysis. Therefore, images showed suspected oil spills were originally identified and selected. Fig. 4 represents the general flow chart of the oil spills detection algorithm.

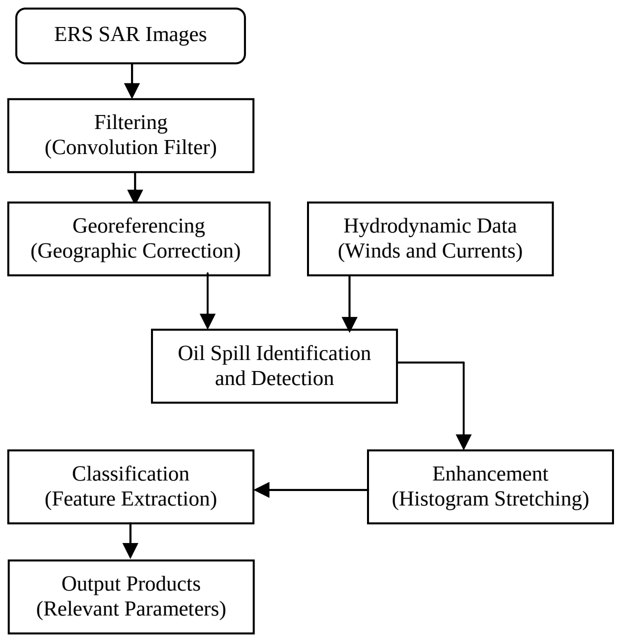

Fig. 4: General flow chart of the oil spills detection algorithm.

The following steps were carried out to process the acquired images:

1) Filtering and georeferencing.
2) Identifying and locating the oil spills on the image.
3) Stretching the image values to increase the contrast between spills and surrounding clear sea.
4) Classification for extracting other relevant parameters.

Filtering of the SAR images was performed to reduce image speckle which is a noise-like phenomena, multiplicative in nature [15] typical for coherent imaging radars. The image data were geographically transformed (georeferenced) to place the oil spill in the correct geographic location. In the next step we locate and distinguish oil spills from other phenomena that dampen out short waves and create dark spots. Further image processing comprises of special enhancement techniques. Such as, spectral stretching using image histogram (i.e. achieving a full radiometric resolution details) to improve the detectability of the oil spills and to emphasize their appearance. Image brightness and contrast were selectively applied to optimize the discrimination of the outlines of the spills. Applying all these procedures, oil spills could be identified as shown in Fig. 5.

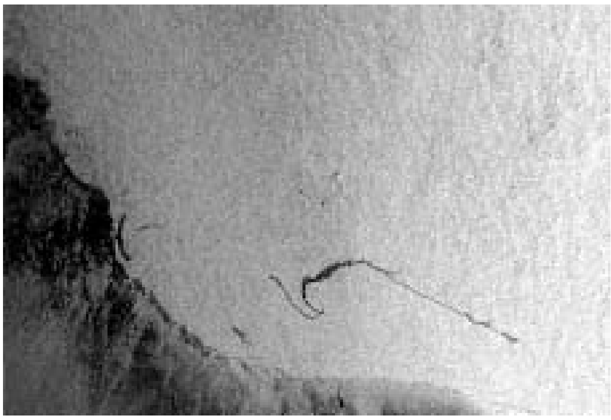

Fig. 5: ERS SAR image acquired on (07/06/2000) with identified oil spills.

After georeferencing, tracing of the oil spill targets and correcting the radiometric range in each image, we enlarge the parts in which the oil spills are visually detected. A training sets of backscatter, textural, and geometrical features are extracted to establish the initial statistical spill model used in the classifier. Based on these extracted features, the classification of all pixels that constitute the oil spill was conducted as shown in Fig. 6. The spill surface area in the image is accurately calculated. Additional relevant parameters like darkest point position and direction, length-width, and number of objects of the spill could also be deduced. All processed oil spill observations in the study area are listed in tables 1.

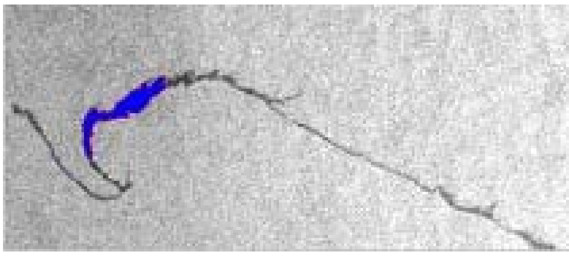

Fig. 6: Classification of enlarged detected oil spill for defining the spill surface area

Table 1: The processed oil spill cases detected by ERS SAR data in the study area.

No	Date of observation	Darkest Point					
		Lon.			Lat.		
1	05/02/2000	32°	18'	04"	31°	24'	51"
2	30/03/2000	31°	35'	36"	32°	22'	27"
3	17/04/2000	31°	22'	56"	31°	46'	12"
4	30/04/2000	33°	19'	05"	31°	58'	19"
5	01/05/2000	32°	46'	55"	31°	54'	42"
6	19/05/2000	32°	60'	45"	31°	45'	10"
7	19/05/2000	32°	27'	11"	31°	49'	36"
8	23/05/2000	30°	38'	48"	32°	07'	54"
9	23/05/2000	30°	27'	40"	31°	54'	18"
10	23/05/2000	31°	12'	39"	31°	43'	02"
11	23/05/2000	31°	15'	00"	31°	46'	31"
12	07/06/2000	31°	48'	51"	31°	47'	21"
13	08/06/2000	32°	15'	34"	31°	50'	11"
14	24/06/2000	32°	20'	07"	31°	31'	56"
15	24/06/2000	32°	33'	35"	31°	22'	06"
16	10/07/2000	32°	47'	54"	31°	10'	38"

Table 1 (Cont.):

The interpretation results indicate that certain areas were facing considerable oil spill concentrations in the navigation routes offshore eastern Nile delta coast. Scattered oil spills are marked by dark patches with a variety of sizes and shapes on the sea surface. Fig. 7 shows numerous distinct oil spill concentrations detected during the period between February-July 2000. A total of 16 spills could be distinguished. They ranged in area from (0.54 to 186.66 km^2) with varying lengths of (1.53 to 45.81 km) respectively. This figure also shows the shapes of these spills, i.e. either elongated segments or short zigzag stripes and some widely spread. Some of these detected observations of oil spills have been confirmed and reported by the Contingency Oil Slick Protection Division of the Egyptian Environmental Affaire Agency. Most of ships anchoring in this area seem to be discharging ballast water containing oil.

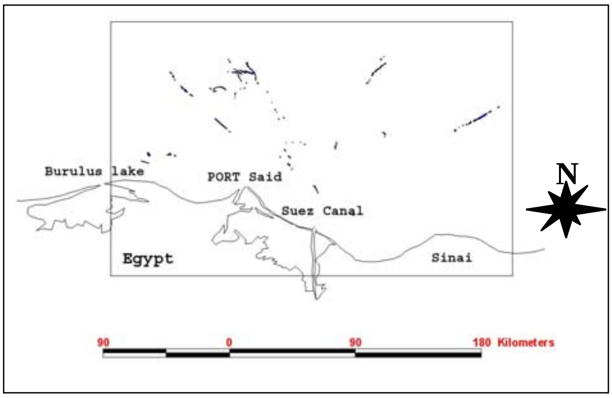

Fig. 7: The distribution of detected oil spills within the Period between February-July 2000.

A data set could be build with relevant information about weather conditions in order to better consider the possible development of the situation. These products help in serving the user community in predicting the time, space and direction of oil spills, before reaching to the nearest coastline, to assess their socioeconomic impacts. As well as, they can be used in the operational decision making tasks related to oil spill emergencies.

NO	Surface of oil spill (Km^2)	Length of oil spill (Km)	Width of oil spill (m)	
			Mean	Max
1	000.540	001.534	322.76	605.68
2	011.514	047.530	401.86	4164.05
3	002.598	005.799	524.72	1958.13
4	015.039	032.996	666.64	1963.13
5	001.999	004.283	515.21	2869.19
6	004.977	016.158	488.53	6115.90
7	002.520	005.291	433.33	830.55
8	186.662	045.811	3896.96	17014.4
9	009.397	011.432	675.01	1434.59
10	001.558	005.300	309.55	607.42
11	003.113	003.037	871.27	1549.48
12	006. 701	007.093	800.00	2717.00
13	001.061	011.921	386.96	1665.62
14	003.263	006.654	413.97	981.56
15	002.012	005.527	381.99	908.52
16	002.895	004.895	506.12	1208.08

5 Conclusions

This study has confirmed that ESR SAR data are useful for marine features mapping such as oil spills detection and identification. They are also useful for visual interpretation of environmentally sensitive areas on a regional scale. The results demonstrate that offshore Nile delta coast faces frequent occurrences of oil spills along the major shipping routes. Considerable oil spill concentrations were found with their accurate locations and thought to be caused by high oil contained ballast water discharged from oil tankers. Oil spills could be identified and recognized using digital image processing techniques based on high quality medium resolution (MRI) SAR images. A total of 11 images were processed in search of oil spills in the period between January to July 2000. The number of identified oil spill cases was 16. The largest detected oil spill in the offshore Nile delta coast has a coverage area of about 128.66 km^2.

Continuous data acquisition is considered as an important factor for understanding the response from the sea surface to different phenomena and frequent changes. The new satellites such as ESA's ENVISAT, Japanese ALOS and the Canadian RADARSATII in conjunction with other widely available satellite data are becoming a vital data sources for oil spill monitoring, early alert and prevention systems. They are making use of larger incidence angles possible and give much better area coverage.

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