Proceedings of the 3rd World Congress on Civil, Structural, and Environmental Engineering (CSEE'18)
Budapest, Hungary – April 8 - 10, 2018
Paper No. AWSPT 134
DOI: 10.11159/awspt18.134

Oil Spill Detection Analyzing "Sentinel 2" Satellite Images: A Persian Gulf Case Study

M. Majidi Nezhad[1], D. Groppi[1], G. Laneve[2], P. Marzialetti[2] and G. Piras[1]
[1]Department of Astronautics, Electrical and Energy Engineering (DIAEE), Sapienza University of Rome
Rome, Italy
meysam.majidinezhad@uniroma1.it; daniele.groppi@uniroma1.it; giuseppe.piras@uniroma1.it
[2]School of Aerospace Engineering, Sapienza University of Rome
Rome, Italy
giovanni.laneve@uniroma1.it; Pablo.marzialetti@uniroma1.it

***Abstract* –** Oil spills near exploitation areas and oil loading ports are often related to the ambitions of governments to get more oil market share and the negligence at the time of the loading in large tankers or ships. The present study investigates one oil spill event using multi sensor satellite images in the Al Khafji (between Kuwait and Saudi Arabia) zone. Oil slicks have been characterized with multi sensor satellite images over the Persian Gulf and then analyzed in order to detect and classify oil spills in this zone. In particular this paper discusses oil pollution detection in the Persian Gulf by using multi sensor satellite images data. Oil spill images have been selected by using Sentinel 2 images pinpointing oil spill zones.
ENVI software for analysing satellite images and ADIOS (Automated Data Inquiry for Oil Spills) for oil weathering modelling have been used.
The obtained results in Al Khafji zone show that the oil spill moves towards the coastline firstly increasing its surface and then decreasing it until reaching the coastline.

***Keywords*:** Sea Pollution, Oil Pollution, Oil spill detection, Sentinel 2.

1. Introduction

In this century, given the growing energy needs of humankind, many national governments and companies increase their researches for oil reserves to deeper waters, transporting oil products across the globe in increasingly larger tankers and huge ships [1] and dispersing annually more than 4.5 million tons of oil into the sea and ocean waters. [2].

This amount of oil pollution not only involves an important impact on marine mammals, sea grasses, coral reefs, and fish populations [3] , but also leads to economic losses in desalination plants, fish farms, and tourism activities in recreational area. On the other hand, oil spill response efforts are globally increasing both facilitating hydrocarbons biodegradation and preventing the more sensitive parts of the ecosystem with oil barriers and forecasting models. Moreover, due to the current energy transition towards renewable energy sources [4-6], human activities on seas and oceans related to the energy sector will include, together with hydrocarbons traffic, other installations like offshore wind farms and wave energy systems that could also foresee the use of storage systems, such as batteries , power to gas options [7-8] and CO2 methanation processes [9] using existing pipelines. In this framework, surveillance is the observation of a spill to gather information that is used to detect, identify, assess and monitor an ongoing spill scenario. Surveillance not only requires observation but also the recording, documentation and dissemination of the information gathered and used as a preparedness measure to monitor areas with potential oil spill risk (water surrounding installations, shipping routes, pipelines) [10]. Oil reflection characteristic not only depends on its class but also on its thickness; moreover its wavelengths are clearly different from seawater [10]. Special features differences are clearly visible and depend on two factors: different oil classes and thickness of oil sample. According to these clear features two spectral bands could be used to characterize an oil spill event [10].

ENVI software is commonly used for the visualization, analysis, and presentation of all types of imagery and includes packages with advanced spectral tools, geometric correction tool, soil, radar [11], and ArcGIS [12] analysis, powerful 3D visualizations, scatter plots elaboration, pixel signatures exploration [13].

Many researches on oil spill modeling and analysis have been conducted in most of the main seas, sub seas and oceans: Marmara Sea [2], Mediterranean Sea [14-16], and coastlines [17-20], Italian Seas [21-24], German North Sea [25], Eastern Mediterranean Sea [26], Lebanon shoreline [27], Mexico Gulf [28], South Aegean (Crete) [29].

The Persian Gulf exports near 18.2 million barrels of oil per day and over 3.5 billion cubic feet of natural gas, that means that near the 18% of world shipments travels through the tankers in the middle east [30].

On the base of this brief framework, the aim of the present work is to analysed Oil spots using multi sensor satellite images in the Persian Gulf. In particular one oil spill event was investigated using Sentinel 2 images in the Al Khafji regions between Kuwait and Saudi Arabia. This study proposes an automatic image processing analysis specifically aimed to detect oil spill events. According the report Kuwaiti media quoted local oil experts declaring that Al Khafji spill was originated in July 2017 from an old 50 kilometer pipeline and experts estimated that about 35,000 barrels of crude oil in this region near the border between Kuwait and Saudi Arabia.

2. Site Description

The Persian Gulf is located between 24° and 30° 30' N latitude and from 48° to 56° 25' E longitude. Persian Gulf is considered an extension of the Oman Sea, The Persian Gulf borders includ: Iran, Saudi Arabia, Kuwait, Qatar, Emirates, Bahrain, Oman and Iraq. The Persian Gulf is connected to the Indian Ocean through Hormoz Strait and Oman Sea from the east while from the west it receives Arvand River running in Khuzestan, Iran. Its average depth is 35 metres and the deepest parts located along the Iranian coast are about 100 metres [31], the Gulf's length is about 865 kilometers and 370 kilometers wide at its widest point [32].

Al Khafji is (Latitude: 28º 25' N and Longitude: 48º 30' E) on the border between Saudi Arabia and Kuwait. The two countries have an agreement to jointly operate the Khafji field oil production (Fig. 1).

Fig. 1: Map of the study area (coordinate reference system of the map is WGS84/UTM zone 39 North).

3. Methods

Multi spectral images exhibit apparent contrasts against surrounding oil-free waters, it depends on a few factors such as the solar viewing geometry, oil type and thickness. This paper studied the oil spill happened in Al Khafji (between Kuwait and Saudi Arabia) detected in july 2017. The multi spectral images have been downloaded from https://scihub.copernicus.eu.

European Space Agency (ESA) has developed and designed a new family of satellite missions called Sentinels (Sentinel 1, Sentinel 2, Sentinel 3) specifically for the operational needs of the Copernicus programme. Sentinel-2 satellite induded: 13 spectral channels, near infrared bands at 10 m resolution, six red-edge/shortwave-infrared bands at 20 m and three atmospheric correction bands at 60 m [33] (Fig 2). This satellite can be used by researchers in various sciences for land monitoring to provide, for instance: imagery of vegetation and forest, soil and water cover, inland waterways, coastal areas and emergency services.

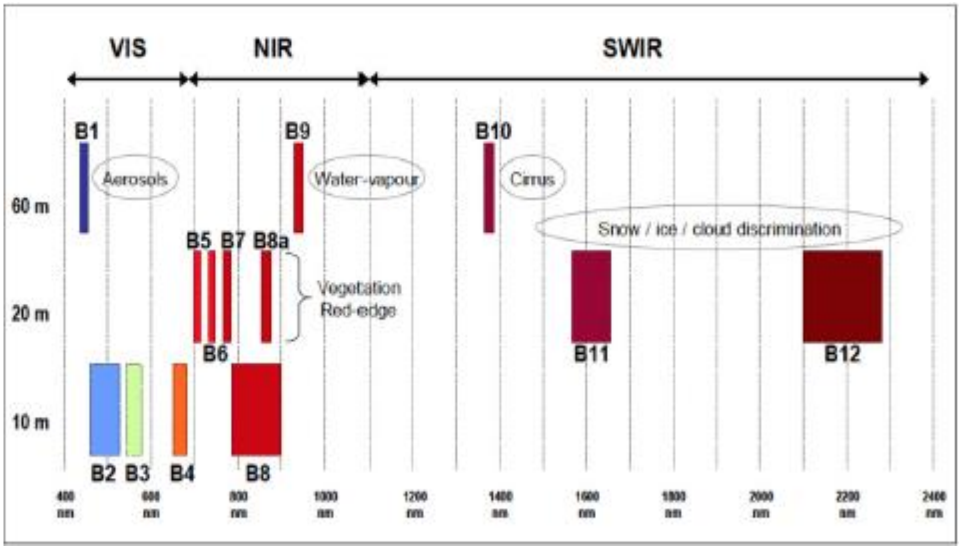

Fig. 2: The bands of Sentinel 2A and 2B [29].

3.1. Datasets

In this study two different type of images have been used, namely Sentinel 2A and 2B. Sentinel 2A and 2B images (Table 1) have initially been used for identifying the oil spill caused by the Al Khafji field. Unfortunately, due to very low wind speeds in the days following the Al Khafji sinking, Sentinel 2A and 2B images could not safely detect the oil spill. For the object-based image analysis of the images, bands 2, 3, 4, 5, 6, 7, 8, 8A, 11, 12 have been used.

Table 1: List of the Sentinel 2 satellite images used.

Geographic Area	Date	Satellite	Image
Al Khafji	2017.05.23	S2A	T39RTM_20170523T073019
Al Khafji	2017.07.17	S2B	T39RTM_20170717T072352
Al Khafji	2017.07.27	S2B	T39RTM_20170727T072611
Al Khafji	2017.08.26	S2B	T39RTM_20170826T072911

3.2. Classification

A first step consists in classifying the spill through the dull area and sheen area models. In the natural evolution of the phenomenon, the release of oil into the sea is characterised by a high degree of emulsion both in the initial stages as well as at the end. The accumulation region is characterised both by a higher thickness and a larger surface as well as by a lower grade of emulsion. The surfacing and the lower degree of emulsion allow us to reasonably assume that the emission capacity of this part of the spill is ruled by the typical emissivity characteristics of the oil, which is significantly lower than the one of water.

3.3. ADIOS 2 Model

ADIOS 2 software (Automated Data Inquiry for Oil Spills) was developed and designed by NOAA, it is an oil weathering tool that models how different types of oil weather in the marine environment.

ADIOS 2 software makes predictions for a maximum of five days. After this days, other processes, such as biodegradation and photo-oxidation happen in oil spill and the program does not model these processes [34][35], downloading this software is free (https://response.restoration.noaa.gov).

4. Results

4.1. ENVI Software

Oil spill Al Khafji in the Persian Gulf is illustrated in (Fig 3), huge patches of oil slicks were found in the Sentinel 2 image collected in July 2017.

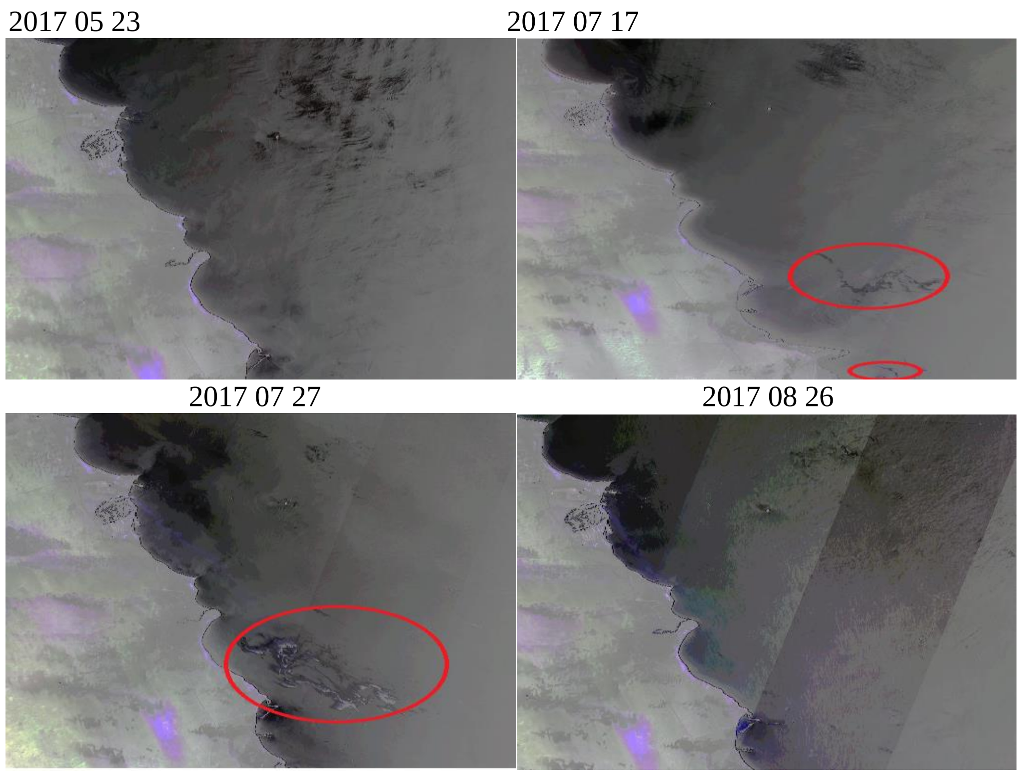

Fig. 3: Sentinel-2 ,chanel 11,12,8A derived true color images for 2017 around the Al Khafji region. The spatial resolution is 20 m. The oil-contaminated areas are outlined with a red circle. For analyses this images we used bands (Red: 11,Green: 12 , Blue: 8A) and filtering with enhance > Gaussian in ENVI software.

Spectrum Matching has been used to identify the spill area, by means of the spectrum matching the direct identification of specific materials has been developed via the extraction of the specific spectral features.

The oil signature was extracted from the image using pictures in Fig. 3, the oil spill is outlined with a red circle, the images relative to the 23rd of May and 26th of August are shown for comparison. The two depressions represent the oil absorption at wavelength of 400 and 1400 µm. The clean water (blue) spectrum shape appeared with steep slob different from oil, soil is easy to discriminate between both materials [36][37].

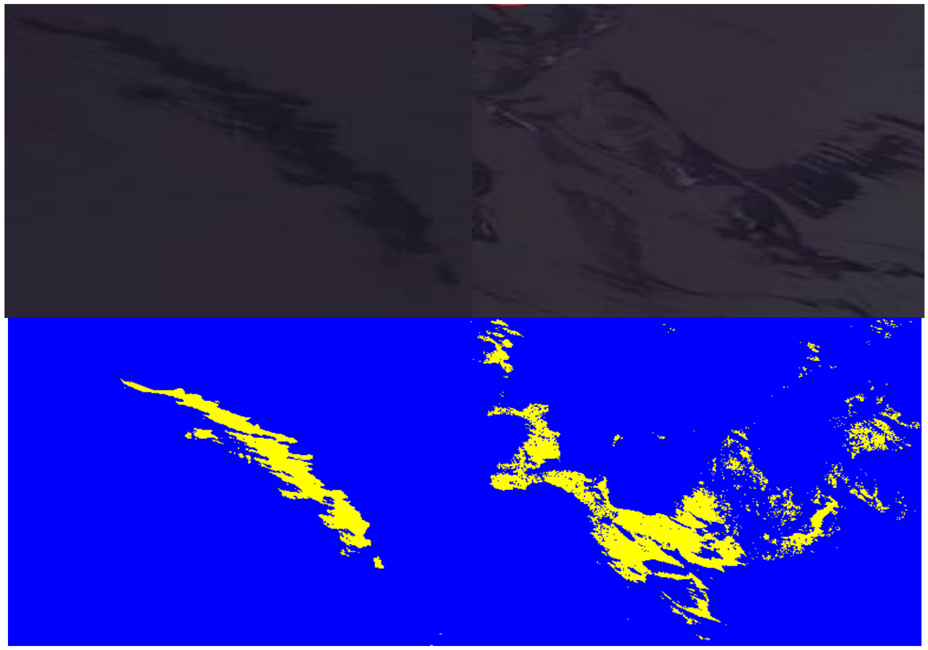

Fig. 4: Classification two examples of dark formations with multi sensor satellite images of Persian Gulf Oil Spill. Interactive colour stretching within the software ENVI 4.8 [34] [5] is used to enhance the contrast between the oil-like features and the background water (blue). Top: original RGB image in scroll, and zoom display windows after classification with ROI tool. Bottom: the same image after Gaussian enhancement. Similar enhancement can be performed in other software packages.

Naturally crude oil spreads irregularly And very soon forms thick patches, which are dark brown/black surrounded by a dark, unbroken thin film. With increasing time, the patches thicken and pile up, evolution brown/orangey brown, while the unbroken film becomes thinner and eventually transforms into sheen, rainbow or metallic appearance [38]. Oil emissivity values are always lower than those of clean water and near dependency between oil emissivity value and oil thickness: the lower the thickness the higher the water content in the oil sample is, so the emission capability would increase until the emissivity contrast, due to emissivity difference, would disappear. However, in calm sunny conditions iridescence may reappear. Thin, unbroken films are clearly visible with a small angle of incidence whereas thick patches are best seen with a large angle of incidence [38] (Fig 4).

4.2. ADIOS 2 Model

ADIOS 2 model not only has been used to evaluate the spreading, evaporation, dispersion, sedimentation, and emulsification of the oil spill but also to assess the effectiveness of clean up options like dispersants, in-situ burning, and skimming. Different types of release scenarios can be simulated in this model and the user is allowed to enter filed data (type of oil, time of release, environmental parameters for example: wind and wave direction, wind speed, water temperature, sediment and tanker parameter) and select the input variables with the resulting uncertainty displayed in the model output [39-40]. In Fig. 5 the assumption and the result of the simulation are showed.

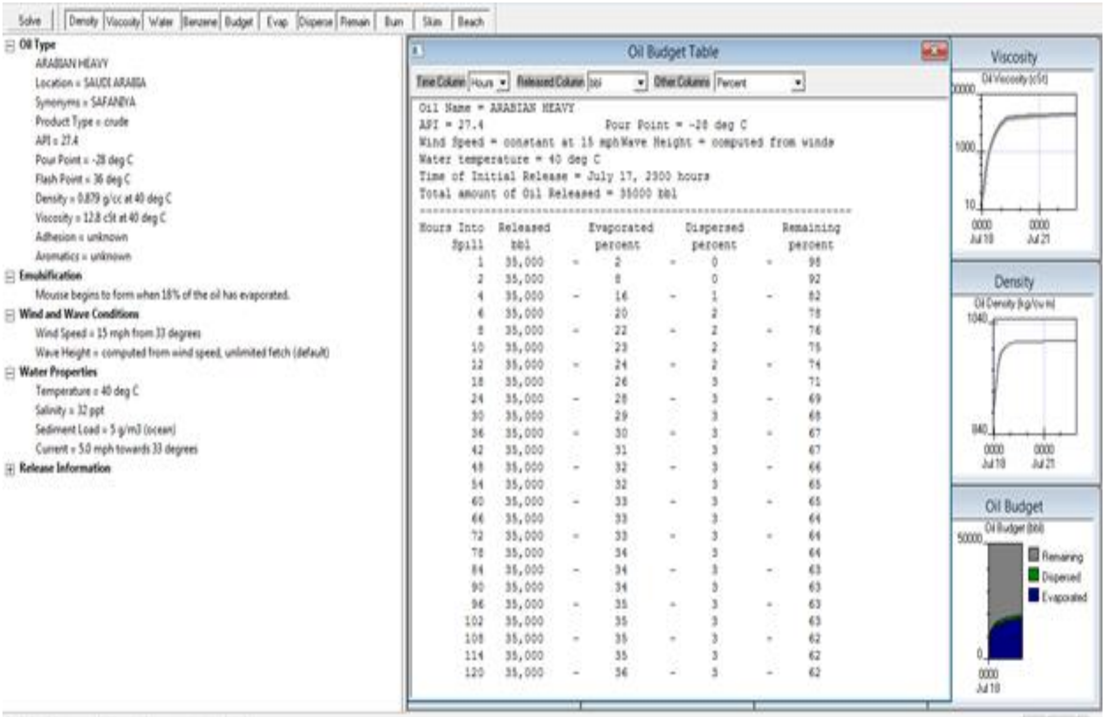

Fig. 5: ADIOS model result for Al Khafji oil spill.

Fig.5 shows results of the simulation with ADIOS 2 model for oil spill event in Al Khafji. For using ADIOS 2 model, user first of all should input some data. A first step consists in choosing the type of oil (oil name) or product spilled between a long list of oil types given in the software. The second step consists in setting the environmental parameters, wind and wave data and then input data about water temperature, salinity and water sediment. At the end, information on the characteristics of the release of oil spill (instantaneous release, continuous release, leaking tank, or contained release) should be provided. After input the data step by step, user can select among different outputs: single, multiple or all graphs, oil budget table (fig 5 in this study) and tables. Various environmental parameters affect the spreading, evaporation, dispersion, emulsification of the oil spill. One of the most important factors of the long term oil spreading is wind speed on the oil spill and surface sea and ocean water, the other important environmental factors that affect the rate of evaporation are wind speed and water temperature. It should be noted, that rate of evaporation will decrease as the slick ages and evaporation and emulsification increase the density and viscosity of the oil spill [39-40].

Results for ADIOS 2 model in Fig 5 show, according with the amount of oil released in Al Khafji zone, as with increasing time (the age of oil spills), evaporation percent increases and remaining percent decreases. Combining satellite images and a model like ADIOS 2 it is possible to follow and forecast the spreading of the oil spill in order to support decisions on the contrasting action to put in place.

5. Conclusion

This study reported the analysis carried out by using satellite optical imagery to detect oil spill in the Al Khafji field in the Persian Gulf occurred on July 2017. ENVI has been used on Sentinel 2 imagery in order to detect oil spills. The software can be applied to Sentinel 2 images, but its results suffer from some errors in shallow water areas. Using this software, the oil spill close to the shore have been successfully detected. The preliminary results are considered successful and consistent, with a high degree of applicability to other Sentinel 2 satellite images. Considering the general factors, the variations in solar/viewing geometry, thickness, oil type, oil slicks indicate bright, dark contrasts in satellite multi spectral images. Satellite measurements prove to be an essential tool for oil detection and monitoring. Most often, active sensor data (SAR, Synthetic Aperture Radar), are used to detect oil spills, determine oil thickness, and track the sources of oil spills. However, these systems suffer of an high rate of false alarms use optical multi spectral imagery is a first option in oil spill detection. The next steps will be to use data images in ArcGIS software and GNOME software to simulate oil spill trends depending on wind speed.

References

[1] Oil Pollution Monitoring, ESA Publications Division, *Remote Sensing Exploitation Division Prepared by: ESRIN*. [Online]. Available: http://www.esa.int/esapub/br/br128/br128_1.pdf

[2] A. Akkartal, F. Sunar "The usage of radar images in oil spill detection," pp. 271-276, 2002. [Online]. Available: www.isprs.org

[3] "Satellite remote sensing of oil spills at sea," International Association of Oil & Gas Producers, 2016.

[4] L. De Santoli, G. Lo Basso, A. Albo, D. Bruschi, B. Nastasi, "Single cylinder internal combustion engine fuelled with H2NG operating as micro-CHP for residential use: Preliminary experimental analysis on energy performances and numerical simulations for LCOE assessment," *Energy Procedia*; vol. 81, pp. 1077-1089, 2015.

[5] L. De Santoli, F. Mancini, S. Rossetti, B. Nastasi, "Energy and system renovation plan for Galleria Borghese, Rome," *Energy Build*. vol. 129, pp. 549-562, 2016.

[6] L. De Santoli, F. Mancini, B. Nastasi, V. Piergrossi, "Building integrated bioenergy production (BIBP): Economic sustainability analysis of Bari airport CHP (combined heat and power) upgrade fueled with bioenergy from short chain," *Renew. Energy* vol. 81, pp. 499-508, 2015.

[7] L. De Santoli, G. Lo Basso, B. Nastasi, "The Potential of Hydrogen Enriched Natural Gas deriving from Power-to-Gas option in Building Energy Retrofitting," *Energy Build*. vol. 149, pp. 424-436, 2017.

[8] B. Nastasi, G. Lo Basso, "Power-to-Gas integration in the Transition towards Future Urban Energy Systems," *Int. J. Hydrogen Energy*; vol. 42, pp. 23933-23951, 2017.

[9] B. Castellani, A.M. Gambelli, E. Morini, B. Nastasi, A. Presciutti, M. Filipponi M et al. "Experimental investigation on CO2 methanation process for solar energy storage compared to CO2-based methanol synthesis," *Energies, vol.* 10, pp. 1-13, 2017

[10] G. Laneve and R. Luciani, "Developing a satellite optical sensor based automatic system for detecting and monitoring oil spills," *2015 IEEE 15th Int. Conf. Environ. Electr. Eng. EEEIC 2015 - Conf. Proc.*, pp. 1653–1658, 2015.

[11] *Getting Started with ENVI*, pp. 1-234, ENVI Versions December, 2009. [Online]. Available: http://www.harrisgeospatial.com/portals/0/pdfs/envi/getting_started_with_envi.pdf

[12] Using ENVI and Geographic Information Systems (GIS) Whitepaper, *ITT Visual Information Solutions*. [Online]. Available: www.ittvis.com

[13] *Get the Information You Need from Imagery*, 2011. Exelis Visual Information Solutions. [Online]. Available: www.exelisvis.com

[14] J. A. J. Madrid, A. García-Olivares, J. B. Poy, and E. García-Ladona, "Managing large oil Spills in the Mediterranean," pp. 1–27, 2015.

[15] M. Marignani, D. Bruschi, D. Astiaso Garcia, R. Frondoni, R. et al., "Identification and prioritization of areas with high environmental risk in Mediterranean coastal areas: A flexible approach," *Science of the Total Environment*, vol. 590-591, pp. 566-578. 2017

[16] F. Gugliermetti, F. Cinquepalmi, D. Astiaso Garcia, "The use of environmental sensitivity indices (ESI) maps for the evaluation of oil spill risk in Mediterranean coastlines and coastal waters," WIT Transactions on Ecology and the Environment, vol. 102, pp. 593-600, 2007.

[17] A. Olita *et al.*, "Oil spill hazard and risk assessment for the shorelines of a Mediterranean coastal archipelago," *Ocean Coast. Manag.*, vol. 57, pp. 44–52, 2012.

[18] G. Harik, I. Alameddine, R. Maroun, G. Rachid, D. Bruschi, D. Astiaso Garcia, M. El-Fadel, "Implications of adopting a biodiversity-based vulnerability index versus a shoreline environmental sensitivity index on management and policy planning along coastal areas," *Journal of environmental management*, vol. 187, pp. 187-200, 2017.

[19] A. Al Shami, G. Harik, I. Alameddine, D. Bruschi, D. Astiaso Garcia, M. El-Fadel, "Risk assessment of oil spills along the Mediterranean coast: A sensitivity analysis of the choice of hazard quantification," *Science of the Total Environment*, vol. 574, pp. 234-245, 2017.

[20] D. Astiaso Garcia, F. Cumo, F. Gugliermetti, F. Rosa, "Hazardous and noxious substances (HNS) risk assessment along the italian coastline," *Chemical Engineering Transactions*, vol. 32, pp. 115-120, 2013.
[21] G. Ferraro *et al.*, “Towards an operational use of space imagery for oil pollution monitoring in the Mediterranean basin: A demonstration in the Adriatic Sea,” *Mar. Pollut. Bull.*, vol. 54, no. 4, pp. 403-422, 2007.
[22] D. Astiaso Garcia, D, Bruschi, F. Cumo, F. Gugliermetti, "The Oil Spill Hazard Index (OSHI) elaboration. An oil spill hazard assessment concerning Italian hydrocarbons maritime traffic," *Ocean and Coastal Management*, vol. 80, pp. 1-11, 2013.
[23] L. De Santoli, F. Cumo, D. Astiaso Garcia, D. Bruschi, "Coastal and marine impact assessment for the development of an oil spill contingency plan: The case study of the east coast of Sicily," *WIT Transactions on Ecology and the Environment,* vol. 149, pp. 285-296, 2011.
[24] F. Cumo, F. Cinquepalmi, D. Astiaso Garcia, "Data gathering guidelines for the mapping of environmental sensitivity to oil spill of the italian coastlines," W*IT Transactions on the Built Environment,* vol. 99 , pp. 119-125, 2008.
[25] A. Chrastansky and U. Callies, “Model-based long-term reconstruction of weather-driven variations in chronic oil pollution along the German North Sea coast,” *Mar. Pollut. Bull.*, vol. 58, no. 7, pp. 967-975, 2009.
[26] T. M. Alves, E. Kokinou, G. Zodiatis, R. Lardner, C. Panagiotakis, and H. Radhakrishnan, “Modelling of oil spills in confined maritime basins: The case for early response in the Eastern Mediterranean Sea,” *Environ. Pollut.*, vol. 206, pp. 390-399, 2015.
[27] G. Coppini *et al.*, “Hindcast of oil-spill pollution during the Lebanon crisis in the Eastern Mediterranean, July-August 2006,” *Mar. Pollut. Bull.*, vol. 62, no. 1, pp. 140-153, 2011.
[28] Gulf Monitoring Consortium, Report on Activities from April 2011 to October 2011. no. April, pp. 1-15, 2011. [Online]. Available: www.skytruth.org
[29] T. M. Alves, E. Kokinou, and G. Zodiatis, “A three-step model to assess shoreline and offshore susceptibility to oil spills: The South Aegean (Crete) as an analogue for confined marine basins,” *Mar. Pollut. Bull.*, vol. 86, no. 1-2, pp. 443-457, 2014.
[30] C. Bayer, “Organization of the Petroleum Exporting Countries OPEC,” ISSN 0475-0608.2017. [Online]. Available: www.opec.org.
[31] S. W. Fowler “Pollution in the Gulf: Monitoring the marine environment,” vol. 358, no. 1992, 1993. [Online]. Available: www.iaea.org.
[32] B. Bojarczyk, “Geopolitics of the persian gulf region,” *Teka Kom. Politol. Stos. Międzynar. – OL PAN*, pp. 800100, 2012.
[33] M. G. C. Gómez, “Joint use of Sentinel-1 and Sentinel-2 for land cover classification: A machine learning approach,” no. 18, Department of Physical Geography and Ecosystem Science Lund University, 2017.
[34] P. Kolokoussis and V. Karathanassi, “Oil Spill Detection and Mapping Using Sentinel 2 Imagery,” *Journal of Marine Science and Engineering.* 2018.
[35] W. Lehr, R. Jones, M. Evans, D. Simecek-beatty, and R. Overstreet, “Revisions of the ADIOS oil spill model,” vol. 17, pp. 191-199, 2002.
[36] R. Jones, “Development of a new oil biodegradation algorithm for NOAA â€™ s oil spill modelling suite (GNOME / ADIOS),” no. March 2016, 2015.
[37] F. Salem and M. Kafato, "Hyperspectral Image Analysis For Oil Spill Mitigation," *22nd Asian Conference on Remote Sensing 2001,* Singapore.
[38] V. Karathanassi, “Spectral Unmixing Evaluation for Oil Spill Characterization,” *International Journal of Remote Sensing Applications,* vol. 4, no. 1, 2014. doi: 10.14355/ijrsa.2014.0401.01.
[39] ENVI Tutorial: Introduction to ENVI Table of Contents. [Online]. Available: http://faculty.wwu.edu/wallin/envr442/ENVI/ENVI-intro.pdf
[40] *Aerial observation of oil spills at sea*. International Association of Oil & Gas Producers. IOGP 2015. [Online]. Available: http://www.oilspillresponseproject.org/wpcontent/uploads/2017/01/Aerial_Observation - 2016.pdf